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Marquart, Leonard Frederick, Ph.D.

The University of North Carolina at Greensboro, 1986

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THE EFFECTS OF DIFFERENCES IN FAT FREE WEIGHT OF ENDURANCE TRAINED ATHLETES ON ENERGY BALANCE AND PHYSICAL WORK CAPACITY

by

Leonard Frederick Marquart

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

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1986

Approved by

Jerry A. Bazzarre

Dissertation Adviser

APPROVAL PAGE

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This dissertation research examined the effects of a 24-week endurance training program on caloric intake, energy expenditure, fat free weight (FFW), and physical work capacity for the upper and lower tertiles. Based on percent body fat at week 0, the upper tertile (n=11) were 15.4 percent and the lower tertile (n=11) were 7.4 percent. At week 0 energy intake and energy expenditure were measured using a seven-day food record and a seven-day activity record, respectively. The sum of four skinfolds was used to measure FFW at weeks 0 and 24. Physical work capacity was measured using a 12-minute run and a bicycle ergometer test at weeks 0 and 24. Mean energy intake (kcal/day) was significantly higher ($p < .01$) among the lower tertile (3208 $\pm$ 832) than for the upper tertile (2204 $\pm$ 751). Oxygen consumption (ml$_2$O /kg/min) was significantly higher ($p < .006$) among the lower tertile (52.7 $\pm$ 10.8) than for the upper tertile (4.04 $\pm$ 7.2). The distance run in miles during the 12-minute run was significantly higher ($p < .002$) in the lower tertile (2.0 $\pm$ 0.1) as compared to the upper tertile (1.8 $\pm$ 0.1). At week 24, oxygen consumption (ml 0_2/kg/min) remained higher ($p < 0.026$) for the lower tertile (56.0 $\pm$ 10.0) than for the upper tertile (45.7 $\pm$ 4.5). From week 0 to 24, only oxygen

consumption (l/min) was significantly higher ($p < 0.04$) for the upper tertile (0.2 ± 0.2). There was no significant difference in FFW loss as a percent of total body weight (TBW) for the lower tertile (0.0 ± 0.3) and the upper tertile (0.0 ± 0) from week 0 to 24. A loss of FFW from week 0 to 24 had no effect on physical work capacity. Although the distance run during the 12-minute run test decreased slightly among endurance athletes who lost FFW as a percent of total body weight, the change was not significant. A submaximal treadmill run to exhaustion at 65-85 percent of maximum heart rate may have been a better measure of the effects of decreased FFW in association with low body fat. Further research using more rigorous procedures is needed to evaluate the objectives of this dissertation.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

Page

CHAPTER

LIST OF TABLES

CHAPTER I

INTRODUCTION

Moderate to high correlations have been reported between performance and percent body fat for various motor and sport skills (Wilmore, in press). Each individual has an ideal body weight for competing in sports; however, the ideal body weight (percent body fat) for competing in any one sport has yet to be elucidated. For example, the ideal body weight for a gymnast would appear to be a weight at which s/he may maintain an optimal level of lean body mass while minimizing fat tissue. Researchers and athletes are interested in determining if there is a "critical" percent body fat at which athletes will lose fat free weight (FFW) despite an adequate caloric intake. While it is difficult to predict the optimal level of FFW and the optimum level of fat tissue for a particular sport, the first step is to determine the "critical" percent body fat at which a decrease in FFW will impair performance in a specific sport.

It has been well established that body composition may be altered through diet (Van Itallie & Yang, 1977), exercise (Pollock, Wilmore & Fox, 1978), and a combination of diet and exercise. However, there is little research as to how and when changes in diet and physical training impair performance. It would appear that for endurance athletes, performance would be impaired as a result of a loss of FFW and impaired energy substrate availability (i.e. loss of free fatty acid release from adipose tissue).

Purpose

The purpose of this research was to evaluate the effects of differences in fat free weight of endurance trained athletes on energy balance and physical work capacity.

Limitations

In order to investigate the above problem, the "ideal" experimental design would be to train a group of individuals to some defined level of ("optimum") performance during which diet would be adjusted until a "maximum" FFW (or low percent body fat) was achieved. At this point, a maintenance period would be followed during which baseline data would be collected (total body weight (TBW), percent body fat, FFW, energy intake, energy expenditure, and physical work capacity). Each subject would then consume an ad libitum diet (protein intake no less than 15 percent of total caloric intake), but would train at a greater frequency and duration of effort until FFW decreased. A significant decrease in FFW would be defined as the percent of FFW reached by each subject at which three measures of mild protein deficiency were reached. These measures would be:

(1) negative N balance

(2) serum albumen < 3.5 g/dl

(3) creatinine/height ratio < 600 mg/24h/m

The "ideal" study design is limiting in two critical ways: (a) the funds, facilities, staff and perhaps "volunteer" subjects are not available to implement the study; and (b) the study may not be "ethically" appropriate since the health risks associated with a very low percent body fat have not been identified. For these reasons, an alternative design and a set of preliminary questions have been developed in order to collect information that may prove helpful in addressing the original problem.

Measures of TBW, percent body fat, FFW, energy intake, energy expenditure and physical work capacity would once again be assessed for each individual as he reached a point of mild protein deficiency. One would be able to identify: (a) at what percent body fat would FFW be compromised with a given mode, frequency, intensity, and duration of exercise; (b) if there was a conservation of energy when one reaches a very low percent body fat; and (c) at what percent body fat would physical work capacity be compromised.

Due to the limitations associated with funds, facilities, staff, and volunteer subjects, an alternative research design was developed. Objectives were developed to evaluate the effects of differences in FFW of endurance athletes on energy balance and physical work capacity.

Objectives

The objectives of this 24-week endurance training program were:

1. To identify subjects with a high and low percent body fat or a relatively high and low FFW.
2. To determine if energy balance is associated with FFW expressed as a percent of TBW.
3. To compare the distribution of FFW loss as a percent of TBW between the upper tertile and the lower terile.
4. To determine if subjects who lose FFW as a percent of TBW will have a decrease in physical work performance.

Data Collection

1. To measure energy intake at week 0.

2 To measure energy expenditure at week 0.

3. To measure energy balance at week 0.
4. To measure body weight at weeks 0 and 24.
5. To measure triceps, biceps, subscapular, and suprailiac skinfolds at weeks 0 and 24.
6. To estimate percent body fat by using the Durnin and Womersley (1974) equation at weeks 0 and 24.
7. To measure FFW at weeks 0 and 24.
8. To measure work performance by using a submaximal bicycle ergometer test (Astrand & Rhyming, 1954) at weeks 0 and 24.
9. To measure work performance by using a 12-minute run (Cooper, 1980) at weeks 0 and 24.

Hypotheses

1. There is no difference between the mean of the upper tertile and the lower tertile for the following variables at week 0:

    a. energy intake (kcal/day)
    b. energy balance (kcal/day)
    c. bicycle ergometer (l/min, ml O_2/kg/min)
    d. 12-minute run (miles)

2. There is no difference in FFW loss expressed as a percent of TBW that occurs in the lower tertile as compared to FFW loss as a percent of TBW that occurs in the upper tertile.

3. There is no association between energy balance and FFW expressed as a percent of TBW.

4. There is no difference in work performance as measured by a bicycle ergometer test among those subjects who lose FFW as a percent of TBW.

5. There is no difference in work performance as measured by the 12-minute run among those subjects who lose FFW as a percent of TBW.

Definitions

Energy balance - Energy intake equal to or greater than energy expenditure as measured by a seven-day average in kcal/day.

Negative energy balance - Energy expenditure less than energy intake as measured by a seven-day average in kcal/day.

Fat free weight (FFW) - Total body weight minus fat weight.

Fat free weight as a percent of total body weight - Total body weight minus fat weight divided by total body weight multiplied by 100.

Upper tertile - The upper one-third of those endurance trained athletes who were ranked on the basis of percent body fat in descending order (15.4 percent mean body fat).

Lower tertile - The lower one-third of those endurance trained athletes who were ranked on the basis of percent body fat in descending order (7.4 percent mean body fat).

CHAPTER II

REVIEW OF LITERATURE

Introduction

Research in the area of nutrition and physical performance has become increasingly important since the number of people who regularly exercise has increased over the past decade. There is little research on the nutritional status of individuals who regularly participate in some form of vigorous exercise. More specifically, there is little research on the effects of diet and exercise on the body composition of endurance athletes.

Although several studies have evaluated the dietary intake of athletes (Blair, Ellsworth, Haskell, Stern, Farquhar & Wood, 1981; Clements & Asmundson, 1982; Short & Short, 1983) and feeding patterns of athletes (Hartung, Foreyt, Mitchell, Vlosek & Gotto, 1980; Kirsh & von Ameln, 1981) there are no known studies reported in the literature that have measured changes in dietary intake relative to energy expenditure during the course of an endurance training program. The combined effects (energy intake and energy expenditure) of an endurance training program (swimming, cycling, running) may exceed one's ability to consume sufficient calories to maintain limited fat stores and lean body mass. Thus, the body may be forced to rely on lean muscle mass to provide additional calories to maintain energy balance.

The main focus of this review of literature will be to examine the impact of an intensive endurance training program on energy intake, energy expenditure, energy balance, and body composition. Since no known research has been conducted to evaluate the effects of an endurance training program on energy balance and subsequent changes in body composition, the review of literature will primarily evaluate those energy balance studies conducted on sedentary and moderately active individuals. The review of literature will be delineated into three major sections including: (a) energy balance studies; (b) effects of food intake on energy expenditure during exercise; and (c) limitations in the measurement of body composition, food intake, and energy expenditure.

Energy Balance

Investigations of food intake and energy expenditure in lean and obese subjects are summarized in Table 1. The most recent study was published by Pi-Sunyer and Woo (1985); while the earliest report dates back to a study by Edholm, Fletcher, Widdowson and McCance (1955). The number of subjects involved in each study ranged from 4 (Pi-Sunyer et al, 1985) to 64 (Edholm, Adam, Healy, Wolff, Goldsmith &

Table 1

Measurement of Food Intake and Energy Expenditure in Lean and Obese Subjects.

Author	n	Subject Description	Mean Age	Sex	Duration of Study	Food Intake	Energy Expenditure	Exercise/ Activity	Mean Energy Intake	Mean Energy Expend.	Mean Energy Balance
Edholm et al. (1955)	12	Cadets similar in height, weight and athletic interest.	19	m	14 days	Food provided unlimited amounts. Food weighed by 3 assistants at a side table. Nutrients calculated from food composition table.	Activities recorded on 18-hour diary forms. Metabolic determination for major activities.	Sitting, standing, lying, marching, arms drills	3414	3416	-2
Durnin et al. (1956)	12	Mothers	51	f	7 days	--	--	Primarily household activities	2100	2090	10
	12	Daughters	20	f					2220	2255	-55
Edholm et al. (1970)	64	Army recruits during initial training	--	--	--	Ate all meals in a common dining hall. Meals were weighed before serving. Energy content determined by food composition table.	Energy expenditure determined by (a) vo_2; (b) BMR; (c) sedentary activities determined by surface area.	Military training, calisthenics, arms drills, marching	4010	3750	-260
Acheson et al. (1980)	12	Subjects living on an Antarctic base	24	m	[illegible]-12 [illegible]ns	Weighed food records (by subjects). Nutrient analysis by bomb calorimetry.	Activity/diary card (factorial method). 24-hour heart rate derived from heart rate/energy expenditure regression equations.	--	3210	3010	200

Table 1

Measurement of Food Intake and Energy Expenditure in Lean and Obese Subjects.

Author	n	Subject Description	Mean Age	Sex	Duration of Study	Food Intake	Energy Expenditure	Exercise/ Activity	Mean Energy Intake	Mean Energy Expend.	Mean Energy Balance
Woo et al (1982)	6	Obese hospitalized for metabolic balance study.	43	f	3 19-day periods: (a) sedentary	Food intake monitored by preweighed serving platters which served as a reservoir from which subjects selected food items to place on plate for consumption. Nutrient analysis by food composition tables validated by bomb calorimetry.	Energy expenditure recorded on a diary card calibrated in one minute intervals. BMR and energy costs of 8 activities measured every 3-4 days.	(a) no exercise	2233[a] (2180)[b]	2221	11 (-41)
					(b) mild exercise			(b) 110% of sedentary expenditure	2305 (2267)	2419	-114 (-152)
					(c) moderate exercise			(c) 125% of sedentary expenditure	2345 (2291)	2714	-369 (-423)
Durrant et al. (1981)	12	(a) obese	27	1m 11f	3 days of no exercise followed by 3 days of exercise for both obese and lean.	Food dispensing machine measured ad lib energy intake. Triplicate samples of food were analyzed by bomb calorimetry.	--	Increased energy expenditure by 100 kcal per day	1196	1214	-18
	4	(b) lean	22	1m 3f					1162	1007	155
Woo et al. (1984)	5	lean subjects hospitalized for metabolic balance study	--	--	3 19-day period: (a) sedentary	Preweighed serving platters to monitor food intake. Same protocol as Woo et al. (1982).	Energy expenditure recorded on diary card. Same protocol as Woo et al. (1982).	(a) no exercise	1812	1720	92
					(b) mild exercise			(b) 110% of sedentary expenditure	2067	1950	117
					(c) moderate exercise			(c) 125% of sedentary expenditure	2159	2205	-49

Table 1

Measurement of Food Intake and Energy Expenditure in Lean and Obese Subjects.

Author	n	Subject Description	Mean Age	Sex	Duration of Study	Food Intake	Energy Expenditure	Exercise/ Activity	Mean Energy Intake	Mean Energy Expend.	Mean Energy Balance
Myfanwy et al. (1984)	6	College-aged students, energy balance study at a university	26	m	5 weeks	All meals were prepared, weighed, and served in a metabolic kitchen. Energy content of food determined by bomb calorimetry.	Energy expenditure recorded on an activity diary. Energy cost of activities determined by indirect calorimetry.	--	3081	3040	41
	6		26	f					2183	2283	-100
Pi-Sunyer et al. (1985)	4	Obese hospitalized for metabolic balance study	--	m	4 10-day periods	Preweighed serving platters used to monitor food intake. Same protocol as Woo et al. (1982), except gourmet foods were served instead of less palatable items.	Same protocol as Woo et al. (1982) and Woo et al. (1984).	Baseline activity 110% baseline 140% baseline baseline			

[a]Determined by bomb calorimetry

[b]Determined by food composition table values

Best, 1970). The mean age of subjects ranged from 19 years (Edholm et al., 1955) to 51 years (Durnin, Blake & Brockway, 1956) while participation for males and females appears to be equally distributed among studies.

Four studies evaluated males only (Acheson, Campbell, Edholm, Miller & Stock, 1980; Edholm et al., 1955; Myfanwy, Riley & Snook, 1984; Pi-Sunyer et al., 1985); whereas, two studies evaluated females only (Durnin et al., 1956; Woo, Garrow & Pi-Sunyer, 1982). Only the study by Durrant, Royston and Wloch (1981) included both males and females, but the effect of gender on energy balance was not evaluated.

The research populations (i.e. free living populations, subjects admitted to a metabolic unit) varied for each of the nine studies. However, the research populations can be delineated into three general categories: (a) a free living population who consumed meals at separate sites (Durnin, et al., 1956); (b) free living populations who consumed meals at a common site (Acheson et al., 1980; Edholm et al., 1955; Edholm, Adam, Wolff, Goldsmith & Best, 1970; Myfanwy et al., 1984); and (c) small populations who were admitted to a hospital or nutrition unit for metabolic studies (Durrant et al., 1981; Pi-Sunyer et al., 1985; Woo et al., 1982; Woo & Pi-Sunyer, 1984).

The duration of the energy balance study for the population consuming meals at separate sites was seven days (Durnin et al., 1956); while the duration of studies involving populations who consumed meals at a common site ranged from 14 days (Edholm et al., 1955) to 6-12 months (Acheson et al., 1980). The duration of the metabolic feeding studies ranged from 6 days (Durrant et al., 1981) to three 19-day periods (Woo et al., 1982; Woo et al., 1984).

Subjects involved in all studies consumed food ad libitum. Methods for measuring food intake varied among those studies where populations consumed meals at a common site. Acheson et al. (1980) required that each subject weigh and record his/her own food intake. Food intake was weighed and recorded before leaving and upon its return to the kitchen (Edholm et al., 1970). In the study by Edholm et al. (1955), food was weighed and recorded by assistants at a side table. Myfanwy et al. (1984) weighed and recorded all food intake in a university metabolic kitchen.

Several techniques were used to measure food intake for those subjects admitted to a metabolic unit. Three research groups (Pi-Sunyer et al., 1985; Woo et al., 1982; Woo et al., 1984) used a preweighed serving platter which served as a reservoir from which subjects selected and placed food items on their plate for consumption. Plate waste and food remaining on the platter were once again weighed following the meals. Durrant et al. (1981) used a food dispensing machine that measured ad libitum food intake.

In earlier energy balance studies (Edholm et al., 1970; Edholm et al., 1955), energy content of food was determined primarily by food composition tables (McCance & Widdowson, 1946; McCance & Widdowson, 1960). More recently, bomb calorimetry was used by (Acheson et al., 1980; Durant et al., 1981; Myfanwy et al., 1984; Pi-Sunyer et al., 1985; Woo et al., 1982; Woo et al., 1984) to determine the energy content of food. Woo et al. (1982) compared energy content of food items derived from food composition tables versus energy content of food items derived by bomb calorimetry.

All researchers used the diary/activity card to monitor energy expenditure in conjunction with measurements of BMR and oxygen consumption for predominant activities that subjects were likely to participate. Edholm et al. (1955) only used an 18-hour per day diary form while all other researchers used the full 24 hours. Acheson et al. (1980) and Myfanwy et al. (1984) determined energy balance through changes in body composition. Acheson et al. (1980) also used the Socially Acceptable Heart Rate Monitoring system (SAMI) to assess energy expenditure.

Subjects involved in the studies by Edholm et al. (1970) and Edholm et al. (1955) participated in military exercises. Durnin et al. (1956) studied housewives and daughters primarily participating in household activities. Durrant et al. (1981), Pi-Sunyer et al. (1985), Woo et al. (1982), and Woo et al. (1984) evaluated energy balance at three levels of energy expenditure (bicycle ergometer): (a) sedentary (no exercise); (b) mild exercise (110 percent of sedentary level); and (c) moderate exercise (125 percent of sedentary level). Pi-Sunyer et al. (1985) used an exercise protocol similar to Woo et al. (1982). Durrant et al. (1981) increased energy expenditure 100 kcal above baseline levels, whereby subjects cycled on a bicycle ergometer.

Caloric intake ranged from 1,162 kcal for 12 obese subjects (Durrant et al., 1981) to 4,010 for 64 army recruits engaged in military training (Edholm et al., 1970). Energy expenditure ranged from 1,214 kcal (Durrant et al., 1981) to 3,750 (Edholm et al., 1970).

Energy intake relative to energy expenditure ranged from a negative energy balance of -369 kcal (Woo et al., 1981). A negative energy balance was reported for all studies involving moderate intensity physical training. Woo et al. (1982) reported the largest negative energy balance (-369 kcal) during moderate exercise (125 percent of sedentary energy expenditure). Army recruits during military training consumed 270 calories less than they expended (Edholm et al., 1970). Obese subjects demonstrated a negative energy balance during exercise (Durrant et al., 1981; Woo et al., 1982) while lean subjects exceeded or maintained energy balance (Woo et al., 1984). However, obese subjects consuming gourmet foods in a metabolic unit had no significant change in energy intake with increasing physical activity (Pi-Sunyer et al., 1985).

Edholm et al. (1955) suggested that a balance between energy intake and energy expenditure was obtained on a weekly basis. There was no correlation between mean energy expenditure and mean energy intake on any given day. Mean energy expenditure on a given day correlated with energy intake two days later. However, Edholm et al., (1970) reported no relationship between energy deficits and the period of time necessary for food intake to balance energy deficits. Woo et al. (1981) demonstrated that small increases in exercise had little effect on energy balance in obese subjects. Moreover, Pi-Sunyer et al. (1985) concluded that sensory stimuli (gourmet food) may be more related to food intake than any inhibitory or stimulatory signals attributed to exercise programs.

A number of energy balance studies have been conducted on both sedentary and moderately active individuals; however, no known research has been reported on the consequences of energy imbalance among endurance athletes. Several questions need to be addressed regarding alterations in body composition consequent to energy imbalances in endurance athletes: (a) will lean muscle mass be compromised due to the athletes inability to maintain energy balance during periods of intensive endurance training; and (b) will there be a decline in lean muscle mass despite an energy balance during an endurance training program? Consequently, further research needs to be conducted on endurance athletes to concomitantly measure energy balance and alterations in body composition during an intense endurance training program.

Effects of Food Intake on Energy Expenditure

Six studies have been summarized in Table 2 involving the acute and chronic effects of exercise or restricted food intake on energy expenditure during exercise. The six studies may be delineated into either acute effects (Elia, Lammert, Aed & Neale, 1984; Garby & Lammert, 1977) or chronic effects (Apflebaum, Bostsarron & Lacatis, 1971; Barac-Nieto, Spurr, Maksud & Lotero, 1978; Bruce, Crosby, Rercheck, Pertschuck, Lusk & Mullen, 1984; Lammert & Hansen, 1982) of excessive or restricted food intake on energy expenditure during exercise. A relatively small number of subjects were used to study the acute responses of excessive or restricted food intake on energy expenditure during exercise (Elia et al., 1984; Garby et al., 1977). Subjects participating in research involving the chronic effects of excessive or restricted food intake

Table 2

The Acute and Chronic Effects of Excessive or Restricted Food Intake on Energy Expenditure at Rest and During Exercise.

Author	n	Subject Description	Age	Sex	Mean Body Weight(kg)	Duration of Study	Feeding Protocol	Measure of Energy Expenditure	Results
Garby et al. (1977)	7	--	26	m	78.0	3 days	Variation in preceeding day's diet (4, 10, 18mj) on vo_2 at rest, and during exercise, before and after a test meal (4mj).	BMR measured following 30 minutes of rest. Oxygen consumption during exercise (36w, 60 revolutions/min. on a bicycle ergometer) was measured during the last 15 minutes of exercise.	No significant effect of the preceeding day's diet on vo_2 during exercise.
Elia et al. (1984)	5	Prestarvation	19-20	m	63.3	4 days	Four day fast taking only distilled water.	BMR and vo_2 during exercise (bicycle ergometer) were measured pre and post starvation.	Before[d] Exercise / During[d] Exercise Prestarvation 5.03 / 20.00 Starvation 4.85 / 21.15 Refeeding 5.02 / 20.12
Apflebaum et al. (1971)								BMR measured with a modified Benidict-Roth apparatus. Meas- urment of vo_2 determined during exercise at the beginning and end of the study.	% difference in vo_2 pre and post diet measurements Cycling[e] / Walking[f] / Climbing Stairs
	9	Control	--	--	Normal weight	15 days	Diet that maintains a constant weight.		-5.0 / 1.1 / 2.2
	8	Overeat	--	--		15 days	Regular diet plus 1,500 kcal of supplements.		19.7[b] / 20.2[b] / 18.8[b]
	41	Restricted diet	--	--	90.9	15 days	220 kcal diet		-12.5[b] / -17.4[b] / -18.4[b]

Table 2

The Acute and Chronic Effects of Excessive or Restricted Food Intake on Energy Expenditure at Rest and During Exercise.

Author	n	Subject Description	Age	Sex	Mean Body Weight(kg)	Duration of Study	Feeding Protocol	Measure of Energy Expenditure	Results		
Barac-Nieto et al. (1978)		3 levels of malnutrition	--	m		1 week	2240 calorie diet (76g fat, 28.8g protein) provided for one week prior to assessment.	Maximum oxygen uptake determined by a modified Balke and Ware protocol.	vo_2 ml/kg.bw	vo_2 ml/mcm	Hbg/dl
	18	Severe Albumen < 2.5g/dl creat/ht < 450mg/24h			W/H < 29kg/m				24.5[c]	104.1[a]	10.0[a]
	20	Intermediate Albumen =2.5-3.5g/dl creat/ht 450-600mg/24hr			W/H < 29-32kg/m				35.4[c]	119.3[a]	12.2[a]
	11	Mild Albumen > 3.5g/dl creat/ht > 600mg/24hr			W/H > 32kg/m				41.7[c]	126.0[a]	15.0[a]
Lammert et al. (1982)	9	Nonobese	30	8m 1f	--	Baseline: determine ususal intake for 14 days Overfeed: 24mj/day for 14 days Semi-starvation: 2.1mj/day for 14 days	Food intake recorded for 14 day period. Energy intake calculated from standard food composition table.	Pedometers used to measure daily energy expenditure. BMR and oxygen uptake during light exercise measured for each of the three diet protocols.	Differences in energy expenditure during exercise before and after the diet treatment. Measured in vo_2 ml/kg.bw Normal: 19.5	Overeat: 24.2	Semistarve: 15.3

Table 2

The Acute and Chronic Effects of Excessive or Restricted Food Intake on Energy Expenditure at Rest and During Exercise.

Author	n	Subject Description	Age	Sex	Mean Body Weight(kg)	Duration of Study	Feeding Protocol	Measure of Energy Expenditure	Results
Bruce et al. (1984)	8	Anorexia Nervosa patients admitted to a hospital	26	f	37.2 67% IBW	--	--	Oxygen uptake monitored at one minute intervals. BMR measured using an abbreviated formula by Weir.	BMR was 82% of predicted values by the Harris Benedict formula using actual body weight. Mean total energy expenditure during exercise was 100 kcals for controls and 55 kcals for anorexic subjects. Oxygen uptake relative to body weight was not significant among control and anorexic subjects.
	6	Controls	29	f	55.6	--	--		

[a]p<.05

[b]p<.01

[c]p<.001

[d]kj/minute

[e]110 kg.m/hr

[f]3.5 kg.m/hr

on energy expenditure during exercise ranged from 8 (Bruce et al., 1984) to 58 subjects (Apflebaum et al., 1971).

Normal weight subjects were used by Elia et al. (1984) and Garby et al. (1977) to evaluate the acute effects of food intake on energy expenditure during exercise while Apflebaum et al. (1971) and Lammert et al. (1982) used normal weight subjects to assess the chronic effects of altered food intake on oxygen consumption during exercise. Bruce et al. (1984) and Barac-Nieto et al. (1978) recruited anorexics and malnourished Columbian rural dwellers to assess the effects of restricted food intake on energy expenditure.

The feeding protocols prior to the assessment of energy expenditure varied widely among studies. Acute effects of food intake on energy expenditure during exercise were measured before and after a four day fast (Elia et al., 1984). Garby et al. (1977) investigated the effects of variations in the preceeding day's food intake (4, 10, and 18 mj) on oxygen consumption at rest and during exercise before and after a test meal (4 mj). Chronic effects of restricted food intake on oxygen consumption during exercise were evaluated following a one week 2,240 calorie diet in subjects who exhibited either mild, intermediate, or severe malnutrition (Barac-Nieto et al., 1978). Apflebaum et al. (1971) evaluated the effects of a 15-day normal diet (maintain constant weight), a 15-day hyper-caloric diet (1,500 kcal above normal diet), and a 15-day semistarvation diet (220 kcal/day) on energy expenditure at rest and during exercise in three groups of subjects. On the other hand, Lammert et al. (1982) used the same group of subjects to investigate the effects of overfeeding (24 mj/day) for a 14-day period followed by 14 days of semistarvation (2.1 mj/day).

Various modes of exercise were used to assess energy expenditure. Apflebaum et al. (1971) used cycling, walking, and climbing stairs to assess energy expenditure while Elia et al. (1984), Garby et al. (1984), and Lammert et al. (1982) used a bicycle ergometer. Barac-Nieto et al. (1978) and Bruce et al. (1984) used a treadmill to measure energy expenditure.

Similar results were obtained by Elia et al. (1984) and Garby et al. (1977) in the evaluation of acute variation in food intake on energy expenditure during exercise. Elia et al. (1984) indicated that there was little change in oxygen consumption during exercise before or after a four-day fast. Garby et al. (1977) reported no significant effects of the proceeding day's diet on oxygen consumption during exericse.

Significant differences in energy expenditure during exercise were observed following various degrees of chronic caloric restriction (Apflebaum et al. (1971) reported significant differences ($p < .01$) in energy expenditure during exercise (cycling 110 kg/m/min, walking 3.5 kg/m/hr, climbing stairs) following either 15 days of overeating (1,500 kcal above normal intake) or 15 days of food restriction (220 kcal/day). Significant differences in VO_{2max} ml O_2/kg/min ($p < .0001$) and VO_{2max} ml/muscle cell mass ($p < .05$) were observed among mild, intermediate and severely malnourished subjects while exercising on a treadmill (Barac-Nieto et al., 1978). Bruce et al. (1984) reported no significant difference in VO_{2max} ml O_2/kg/min between controls and subjects with anorexia nervosa.

In the two acute studies involving the effects of food intake on energy expenditure during exercise, Elia et al. (1984) concluded that a 4 day fast had no effect on resting or exercise metabolic rate while Garby et al. (1977) also concluded that the proceeding day's diet had little effect on oxygen consumption during exercise.

The conclusions varied considerably among the studies involving the chronic effects of excessive or restricted food intake on energy expenditure during exercise. Bruce et al. (1984) reported no differences in VO_2 ml O_2/kg/min among control subjects and anorexic subjects; whereas, Apflebaum et al. (1971) indicated that energy expenditure increased by 12-29 percent following 15 days of overeating (regular diet plus 1,500 kcal/day) and decreased by 12-17 percent following a restricted diet (220 kcal/day) for 15 days. Lammert et al. (1982) suggested that body energy content may in part be attributed to changes in the efficiency of energy utilization, whereby responses to energy intake varies considerably among individuals. Barac-Nieto et al. (1978) concluded that chronic nutritional deficiencies result in decreased muscle cell mass, hemoglobin, oxygen consumption and thus a decrease in physical work capacity. Decreased muscle cell mass and hemoglobin accounted for 83 percent of the variation in VO_{2max} among malnourished subjects. Barac-Nieto et al. (1978) suggested that lower VO_{2max} may be attributed to limitations arising from oxygen delivery to the working muscle via decreased cardiac contractility, reduced stroke volume, and decreased cardiac output.

The review of literature regarding the effects of a chronically restricted food intake on energy expenditure during exercise suggests several conditions may effect energy balance studies of endurance athletes. In the case of an endurance athlete whose high energy expenditure exceeds his/her ability to consume a sufficient amount of calories (rather than a reduction in caloric intake to create an energy deficit and thus a decreased BMR), is there still a conservation of energy (decreased BMR) to assist in the maintenance of energy balance? Will the body become more efficient in maintaining energy stores during exercise at a critical percent body fat. Critical percent body fat is defined as the percent body fat at which FFW is used disproportionately for energy needs as compared to the use of FFW at higher levels of body fat.

Although there is a need to evaluate alterations in body composition in endurance athletes, there are severe limitations associated with the accurate measure of body composition, food intake, and energy expenditure. In the remaining sections of this review of literature the limitations and practicality of available methods for assessing body composition and the measure of energy balance will be assessed.

Body Composition

Wilmore (1983) has summarized findings from 55 studies involving alterations in body composition following physical training. The magnitude of change in total weight, fat weight, and lean body weight varied directly with the frequency, intensity, and duration of the activity, and the duration of the study. Numerous studies have been conducted in order to evaluate changes in body composition while training for a specific endurance activity such as swimming (Conger & MacNab, 1967; Novak, Hyatt & Alexander, 1968; Sprynarova & Parizkova, 1971; Wilmore, Brown & Davis, 1977), cycling (Girandola, 1976; Pollock, Miller, Jr., Kendrick & Linnerud, 1975; Smith & Stransky, 1976), and running (Barnard, Grimditch & Wilmore, 1979; Costill, Bowers & Kammer, 1970; Lewis, Haskell, Klein, Halpern & Wood, 1975; Malina, Harper, Avent & Campbell, 1971; Pollock, Miller & Wilmore, 1974; Rusco, Hora & Karvinen, 1978; Wilmore & Brow, 1974). However, inherent factors associated with the measurement of body composition severly limit the researcher's ability to accurately quantify alterations in body components which may be attributed to physical training.

The measurement of body composition has traditionally relied upon the two-component system which was derived from direct analysis of adult cadavers. There are a number of limitations associated with the two-component system for measuring body composition since few studies have assessed the variability in FFW among individuals. In the following sections the limitations of the two-component system will be discussed with regard to the assumptions underlying the hydrostatic weighing procedure.

Evidence derived from both animal and human studies has led to the development of the two-component system for body composition analysis namely FFW and fat weight (FW) (Keys & Brozek, 1953). The primary advantage of the two-component system is that only one constituent, FFW, needs to be calculated from which the relative FW and FFW may be determined. However, the major limitation of the two-component system for body composition analysis is the relatively large potential for variability of FFW, both with respect to component densities as well as the proportionality of the components. Thus, the variability in FFW may affect the true measure of percent body fat while utilizing indirect measures of body composition.

Lean body mass (LBM) and FFW are often used interchangeably; however, the two terms are not synonymous. Lean body mass constitutes bone, muscle, minerals, water, and essential lipid necessary for cell membrane and nervous tissue formation as well as other physiological functions. On the other hand, FFW includes all body components except lipids (Behnke, Feen & Welham, 1942). FFW may be of more practical use than LBM since many of the analytical techniques for measuring body composition are determined by the difference between total body weight minus estimated FW.

Indirect measures of body composition (i.e. hydrostatic weighing) are based upon several studies that have directly analyzed the chemical composition of adult human cadavers (Forbes, Cooper & Mitchell, 1953; Mitchell, Hamilton, Steggerda & Bean, 1945; Widdowson, McCance & Spray, 1951). There are, however, limitations associated with the assumption that indirect measures of body composition may be based on the direct measurements of body composition in a small number of cadavers.

Keys and Brozek (1953) summarized the direct measure of body compositional data derived from one female and four male cadavers (Table 3). Of the five cadavers analyzed,

Table 3

Body Composition From the Direct Analysis of Human Cadavers[a]

Author	Age	Sex	Height (cm)	Weight (kg)	% Total Weight Water	Fat	Protein	Ash	% Fat-Free Weight Water	Protein	Ash
Mitchell et al. (1945)	35	m	183	70.6	67.9	12.5	14.4	4.8	77.6	16.5	5.5
Widdowson et al. (1951)	42	f	163	45.1	56.0	23.6	14.4	7.6	73.2	18.8	9.9
	25	m	179	71.8	61.8	14.9	16.6	7.5	72.6	17.5	8.8
	48	m	--	63.8	81.5	1.1	12.8	4.9	82.4	12.9	5.0
Forbes et al. (1953)	46	m	163	53.8	55.1	19.4	18.6	5.4	68.4	23.1	6.7

[a]Adapted from Keys et al. (1953).

only two (a 42 year old female and a 46 year old male) were healthy, well-nourished individuals who suddenly died and whose bodies were immediately analyzed. At the time of analysis, the remaining bodies (25, 48, and 35 year old males) were severely malnourished due to prolonged illnesses. There was considerable variability in percent body fat, percent water content of fat free mass (subjects corresponding to 82.4 and 77.6 percent water content of fat free mass were edematous), and ash content as a percent of total body weight and FFW.

Evidence based upon the direct measures of body composition (Forbes et al., 1953; Mitchell et al., 1945; Widdowson et al., 1951) indicates that there is considerable variability in FFW among individuals. Keys et al. (1953) concluded that in the normally hydrated individual, the variability of density in FFW cannot lead to errors of greater than 2-3 percent. Considering the small population (n=5) and the poor nutritional status of three subjects, the assumption that FFW may not vary more than 2-3 percent among individuals lacks rigorous proof.

Preliminary work by Martin, Drinkwater, Clarys and Ross (1981) suggests that there is a greater variability associated with FFW among individuals than previously expected. Mean bone density ranged from 1.18 to 1.33 g/ml at 20° C (i.e. mean bone mass ranged from 17.5 to 24.9 percent of total adipose tissue free mass in 12 male and female cadavers). Muscle mass as a percent of adipose tissue free mass ranged from 45.6 to 59.7 percent. Although this preliminary data may not be comparable to earlier body composition studies, there appears to be relatively large interindividual differences in FFW. The implications that FFW may vary considerably among individuals further compromises the validity of indirect measures of body composition that are based on the two-component system.

Although hydrostatic weighing has been used as the standard to validate new methods for measuring body composition, there is increasing evidence that potential error may be associated with the assumptions underlying the method (Wilmore, 1980). Certain basic assumptions were made when using the two-component model (i.e. hydrostatic weighing) for measuring body composition; whereby, total body mass is delineated into FW and FFW. The hydrostatic weighing procedure assumes that: (a) fat composition and fat density is similar among individuals; (b) FFW is relatively stable with little interindividual variability in water, bone, muscle, and mineral content; (c) environmental influences including nutrition and exercise have only minor effects on FFW; and (d) the individual differences from the "reference man" vary only in fat content (Wilmore, 1984). Therefore, an accurate measure of body composition while using the hydrostatic weighing procedure assumes that all four assumptions are true.

Present evidence indicates that the assumptions underlying the hydrostatic weighing procedure may not be as appropriate as Keys et al. (1953) once assumed. Variations in fat density are assumed to be small among individuals between sexes and at various locations in the body. Human body fat has been reported to have a density of .9000 g/ml at 37° C (Fidanza, Keys & Anderson, 1953). FFW is assumed to have a density of 1.10 g/ml at 37° C, based on conclusions drawn from the direct analysis of cadavers (Forbes et al., 1951). However, the biological variation in chemical composition of FFW appears to be the most limiting factor in the usefulness of the two-component system for measuring body composition. Based on the conclusions drawn from the direct analysis of cadavers (Forbes et al., 1953; Mitchell et al., 1945; Widdowson et al., 1951), estimates of the biological variation among individuals is approximately 2-3 percent. Furthermore, preliminary research by Martin et al. (1981) has suggested that interindividual differences in water, bone, muscle, and mineral content may vary more than once expected.

Nutritional status, exercise, and age may further increase the variability in FFW among individuals. Direct analysis of cadavers indicates that FFW varies considerably among well nourished and malnourished subjects (Forbes et al., 1953; Mitchell et al., 1943; Widdowson et al., 1951). Malnourished subjects had a FFW consisting of a lower mineral and higher water content than the well nourished subjects. Low calcium and vitamin D intakes may lead to a decreased mineral content in bone (Lutwak, 1974). Low caloric and protein intakes may alter FFW since muscle tissue will be utilized to maintain the energy requirements for more essential tissues (Lamb, 1984).

Significant changes in body composition may result from regular physical activity and may occur with or without dietary changes (Pollock et al., 1978). Exercise may induce hypertrophy of muscle tissue, decrease fat depots, increase bone density, and increase blood volume (Pollock et al., 1978). Acute responses to exercise may also occur. Water loss (dehydration) is generally accompanied by severe exercise of prolonged duration.

The acute and chronic changes in body composition as a result of regular exercise may conceivably alter FFW and thus, may increase the variability in FFW among individuals. A dehydrated endurance athlete is a good example whereby the density of FFW may be altered due to strenuous activity. Alterations in FFW (dehydration) may affect three of the four assumptions underlying the hydrostatic weighing procedure (Lohman, 1984). Buskirk and Mendez (1984) suggested that the inclusion of total body water assessment while using the hydrostatic weighing procedure may account for some of the intra and interindividual variation in water content. Lohman (1984) also suggested that assuming a body composition of 4 percent fat, 73 percent water, and 19 percent protein, an increase in muscle tissue (density 1.062 g/cc) from 40 to 44 percent of the FFW would decrease the fat free density from 1.1000 to 1.0974 g/cc. Therefore, there would be a net decrease in body density of 0.0021 g/cc despite an increase in muscle tissue. Changes in body water and muscle tissue may alter FFW in athletes as opposed to the body composition of the reference man.

The formulas developed by Brozek, Grande, Anderson and Keys (1963) and Siri (1961) were proposed for the body compositional analysis of young adult males. The Siri equation was based on the assumption that fat free body density was 1.100 g/cc and fat density was .900 g/cc. The Brozek equation was based on the chemical composition of the reference caucasion male 25 years of age with a density of 1.0629 g/ml at 37° C (Brozek et al., 1963). Since both the Siri and Brozek equations were proposed for the reference young adult male, it is inappropriate to use these formulas to determine body composition in other populations such as the aged, various racial groups, children, and athletes (Lohman, 1984). Therefore, further research needs to be conducted to develop age and sex specific formulas to more accurately measure body composition in these populations.

There are other methodological limitations associated with the hydrostatic weighing procedure to assess body composition. The subject must cooperate fully by submerging underwater while expelling all but the residual volume of air from his/her lungs. The observor must be well trained to obtain accurate densitometry readings. It is difficult to assess and to account for the quantity of gas that may be trapped in the stomach or gastrointestinal tract. Determination of the residual volume is another source of error (Wilmore, 1969). The hydrostatic weighing procedure is time consuming and is impractical for large clinical or epidemiological studies. Finally, it is expensive to buy the necessary equipment to carry out the densitometry procedure.

The two-component method for estimating body composition may systematically underestimate or overestimate body fatness since the constituents of FFW (water, bone, muscle, mineral) do not appear to be constant among individuals. Variability in the FFW for white college-aged males is believed to be ± 3 percent; however, the variability in other populations (children, women, athletes, disabled, and the elderly) has yet to be elucidated (Lohman, 1984). Further research needs to be conducted to accurately quantify the components of FFW.

Due to the limitations associated with the two-component system for measuring body composition, it is very difficult to accurately quantify alterations in body composition (i.e. muscle tissue, bone, water, mineral). The inability to determine alterations in FFW consequent to a negative energy balance in athletes is one of the major limitations to using the two-component system for measuring body composition. Unless facilities are available to measure each of the body components, true alterations in the constituents of FFW may not be assessed. An increase or decrease in FFW may be attributed to alterations in each of the four components of FFW; therefore, a researcher may not conclude that an alteration in FFW may be attributed to an increase or decrease in lean muscle tissue. The ideal method for measuring body composition is to assess each of the major body components separately. By measuring each of the body components separately, limitations associated with variations in FFW may be minimized.

Skinfold Measurements

Skinfold measurements are the most common method of assessing body composition in clinical and epidemiological studies. Anthropometric measurements are quick, easy to administer, require no special cooperation from the subject, and are relatively inexpensive. There are, however, several factors which limit the usefulness of skinfold measurements in the assessment of body composition. According to Lohman, Pollock, Slaughter, Brandon and Boileau (1984), the validity and reliability of skinfold measurements may be affected by the prediction equation (i.e. population specific vs. generalized equations), the anthropometrist (inter and intraobserver error), and the brand of calipers.

Skinfold measurements are based on the assumption that adipose tissue is 50 percent subcutaneous and 50 percent internal (Beal, 1980). Subcutaneous fat is not always uniformly distributed. Subcutaneous fat may vary 20-70 percent from one subject to another (Durnin & Womersley, 1973). Subcutaneous fat varies as a percentage of total fat due to differences in inter and intramuscular fat and due to differences in the amount of fat deposited in and around organs.

Individual, sex, and age variations in patterns of fat deposition affect the degree to which skinfold measurements accurately reflect total body fat (Lohman, 1981). Since the composition of the human body varies significantly with respect to age and sex, the most appropriate sites for skinfold measurements must, therefore, be selected in accordance with the subject's age and sex (Durnin et al., 1973).

Extensive research has been conducted to develop population-specific formulas to measure body composition in selected populations of young and middle-aged males (Durnin & Rahaman, 1967; Sloan, 1967) and females (Sloan, Burt & Blyth, 1962; Young, 1964). However, there are several limitations to population-specific equations for measuring body composition. In order for population-specific equations to accurately assess body fat, the research sample must be representative of the population from which the equation was developed. Error is also associated with the assumption that body density is linearly related to skinfold fat (Pollock & Jackson, 1984).

Jackson (1984) indicated that for subjects varying greatly in age and body fatness, the relationship between body density derived by hydrostatic weighing and seven skinfold measures was curvilinear rather than linear. Although the standard error of the mean is similar for both the linear and quadratic equation (3.3-4 percent), the standard error of measurement differs significantly at the population extremes (age, sex, fat level) for the linear model (±5 percent) as opposed to the quadratic equation (±3.3-4 percent). In addition, the linear model generally underestimates body fat in fatter groups and overestimates in leaner groups (Lohman, 1981; Pollock, Hickman, Kendrick, Jackson & Linnerud, 1976; Pollock, Laughridge, Coleman & Linnerud, 1975).

Due to the limitations associated with population-specific equations, several researchers have developed generalized equations to measure body composition over a more heterogeneous population (Durnin & Womersley, 1974; Jackson & Pollock, 1978; Jackson & Pollock, 1982; Jackson, Pollock & Ward, 1980). The primary advantage of generalized equations based on skinfold measurements is that they are more valid for a heterogeneous population (i.e. variation in fatness, age, and the nonlinear relationship between body density and subcutaneous fat) than for the population-specific equations. Therefore, the generalized equation provides a more accurate means for assessing body fat in a diverse population than for population-specific equations.

The anthropometrist may account for substantial error associated with the skinfold technique for measuring body composition. Measurement error inherent to the anthropometrist is classified into two major categories. First, intraindividual error is the amount of variance associated with repeated measures on the same skinfold sites that are recorded by the same observer. Second, interindividual error is the variance between two or more observers when repeated measures are obtained for the same skinfold site(s). Several factors may account for the intra and interindividual variations in skinfold measurements which include experience, the site of measurement, and measurement technique. Considerable variation exists among experienced anthropometrists for most skinfold sites (Burkenshaw, Jones & Krupowicz, 1973; Jackson, Pollock & Gettman, 1978). Jackson and Pollock (1984) indicated that intraobserver reliability (r=0.90) may be obtained with good instruction and several practice sessions.

Selection of skinfold sites affects the measurement error within and among observers. Lohman (1981) suggested that the selection of skinfold sites is the most important factor associated with interobserver error. Lohman, et al. (1984) reported that the greatest error appeared to be at the thigh and suprailiac skinfolds; while the least amount of error was recorded for the tricep and subscapular fat folds.

The technique used by the observor will affect both the intraobserver and interobserver variation. It is important for the anthropometrist to be properly trained regarding the specific protocol established for the given equation that will be used. Katch and Katch (1980) suggested that a minimum of 2-5 skinfold measurements should be obtained from each site to reduce intraobserver error. Several researchers have indicated that the sum of skinfolds may be used rather than one skinfold site to reduce interobserver variation (Jackson et al., 1982; Womersley, Durnin, Boddy & Mahaffy, 1976). Significant error has been attributed to gripping the skinfold, placement of the calipers, and the delay in reading the skinfold measurement (Keys et al., 1953). It is also recommended that the same anthropometrist collect skinfold measurements on the same individual over two or more points in time in order to reduce interobserver error.

Different brands of skinfold calipers may lead to differences in skinfold fat measures. Lohman et al. (1984) reported that the brand of calipers may affect the degree of error associated with the use of skinfold measurements for determining body composition. The Harpenden calipers underestimated skinfold values compared to the Lange calipers for five sites: triceps skinfold, 24 percent; subscapular skinfold, 28 percent; suprailiac skinfold, 49 percent; abdominal skinfold, 26 percent; and thigh skinfold, 16 percent. However, Sloan et al. (1972) reported no significant difference in fat fold measures at any site among Harpenden, Lange, and MNL skinfold calipers. Womersley, Durnin, Armstrong and Friskey (1973) also reported no significant differences among calipers for measuring skinfold sites. Further research needs to be conducted to assess the variation in skinfold calipers used to assess fat fold measures. At the present time it is prudent to use the same type of skinfold calipers that was used to develop the equation.

In summary, there are a number of limitations associated with the use of skinfold measurements in assessing body composition. Individual, sex, and age variations in patterns of fat deposition affect the degree to which skinfold measurements accurately reflect total body fat. The anthropometrist, the selection of skinfold sites, and the brand of calipers all affect the validity and reliability of skinfold measurements. The inability of population-specific equations to estimate body composition in a random sample of the general population has led to the development of generalized equations. Generalized equations have been more accurate in estimating body composition in heterogeneous populations. There is, however, a need to conduct further research to develop valid and reliable equations for defined groups (aged, athletes, handicapped) by expanding the generalized equations or develop new group specific equations. Until specific equations are developed for athletes, it may not be prudent to assume that skinfold measurements provide a valid estimate of percent body fat. Nevertheless, skinfold measurements provide a practical means of evaluating the relative distribution of body fat during an endurance training program.

Dietary Methodology

Dietary studies are used to determine the sources and amounts of nutrients consumed, and are an integral part of any nutritional assessment program. The reasons for collecting dietary intake data include the following: (a) to provide an estimate of the average nutrient intake, food intake, or usual food habits of individuals; (b) to provide a basis for making comparisons between groups; (c) to identify dietary deficiencies or excesses by comparing the average food or nutritional intake of groups of individuals to dietary standards; (d) to obtain nutrient intake on a given individual for correlations with clinical or biochemical measurements obtained on that individual; and (e) to provide a means for establishing appropriate dietary intervention programs (Christakis, 1973; Committee on Food Consumption Patterns; Marr, 1971).

In selecting the most appropriate dietary methodology, certain factors inherent to the research design as well as those factors that are attributed to the dietary methodology itself must be considered. Factors inherent to the research design include the purposes and objectives for collecting dietary data (food intake, food patterns, nutrient intake), population characteristics, and available resources. The usefulness of each dietary methodology depends upon the validity, reliability, and the efficiency and accuracy in converting food intake data into nutrient values.

Callmer, Haroldsdotter, Loken, Seppanen and Solvoll (1985) have proposed that the selection of a method for collecting food intake information depends upon the purposes of the "dietary output data" (nutrients, food sources and/or meal patterns). Four levels of "dietary output data" have been identified: level I, mean consumption of a group; level II, mean and distribution of consumption in a group; level III, the relative rank order of the consumption of an individual within a group; and level IV, the absolute magnitude of the consumption of an individual. One should select the lowest possible level to fulfill the objectives of the proposed research, since with each additional level, there is an increase in costs, greater demands placed on the subjects, and usually a lower rate of cooperation (Callmer et al., 1985).

Callmer et al. (1985) have suggested dietary methodologies that would be appropriate to measure food consumption at each level of "dietary output data". The mean consumption for a group (level I) may be determined through the use of a 24-hour recall. The mean and distribution of food intake (level II) for a group may be determined through repeated 24-hour recalls or through various forms of repeated food records. The relative magnitude (rank order) of food consumption, for an individual (level III) depends on the ratio between the intraindividual and the interindividual variation in food consumption for the group being investigated (Marr, 1971). Therefore, the level of dietary output data depends on the number of repeated days of food intake to minimize intra and interindividual error. A duplicate weighed food record for a nine day period has been proposed as a method of accurately measuring fat intake at level III, while it is doubtful whether any food intake method will accurately quantify absolute food intake at level IV without systematic error. However, the weighed food record has provided the most accurate measure of quantifying absolute measures of food intake.

There are basically two dietary methodologies available for collecting food intake information from individuals. Dietary records consist of records by weighing (scale), records by household measure and records by menus (Bazzarre & Myers, 1978). Dietary recalls require that a trained interviewer obtain information regarding a subject's actual food intake (24-hour recall), usual dietary intake (diet history), or food frequency.

The target population is of major importance for the selection of the method used for dietary research. The number of subjects, age, sex, educational level, cooperation, and available time for recording dietary intake must be considered (Christakis, 1973). Women are better able to recall food intake than men, and younger individuals are able to recall food intake better than old (Campbell & Dodds, 1967). Thompson (1968) indicated that cooperative and intelligent subjects were prerequisite to the successful recall of prior food intake. Dietary surveys involving a random sample of the general population (children, teenagers, adults, elderly) should require little time and cooperation from the subject. In the case of specific groups, every effort should be made to adapt the methodology to the existing characteristics of the population (Callmer et al., 1985).

The usefulness of a dietary method is determined by its validity and reliability. The validity of a method (whether a method measures what it is intended to measure) can only be tested by comparing it to a method with indisputable accuracy. Reliability refers to the ability of an instrument to reproduce the same results when used repeatedly in the same situation. The validity and reliability of the dietary food record and the 24-hour recall will be discussed in the following paragraphs in this review of dietary methodologies.

Weighed food records are considered to be one of the more valid measures for determining food intake in individuals (Marr, 1971). Weighed food records are generally used for metabolic feeding studies since a very precise measure of food intake is required. There are, however, several factors that limit the usefulness of the weighed food record for measuring food intake. Weighing all food items requires a high degree of cooperation from the subject, and thus, a poor response rate may result. In addition, weighing may alter subject's eating patterns since they may become very conscious of foods consumed (Bazzarre et al., 1978).

The seven-day food record (household measures) has been suggested as an accurate measure of usual food intake over various points in time while collecting food intake data on cooperative, reasonably intelligent, and highly motivated individuals (Bazzarre et al., 1978). Similar results for several nutrients have been reported for records by weighing and for records by household measures. Todd, Hudes, and Calloway (1983) have reported no differences in mean energy and protein intake recorded by a one-day food record (weighed measure) and a one-day food record (household measures).

Food intake may vary considerably depending on the household measure used to estimate portion size (Van Staveren et al., 1985). Although there are large variations in the range for household measures (portion sizes) among subjects living in 30 households, the means for the populations were very similar to the standard measure. For example, the portion size for a standard measure of tea (125 cc) ranged from 110-175 cc while the mean for the population was 128 cc. Therefore, household measures for estimating food intake appears to provide accurate estimates of food intake in a relatively large population.

Although food records provide a means of accurately measuring "usual" food intake, the length of time for data collection may be an important consideration. Stuff, Garza, Smith, Nichols and Montandon (1983) observed good agreement between the three-day food record and the seven-day food record. However, they also concluded that the seven-day food record provided the best compromise between obtaining accurate information and minimizing the imposition on the subjects' lifestyle. On the otherhand, Gersovitz, Madden, and Smickalas-Wright (1978) reported that two methodological problems may affect the validity of the seven-day food record. By day seven, food records were returned by the more highly educated group, thus causing a bias in the sample. The accuracy of the food records declined by the fifth, sixth, and seventh day. Although 85 percent of the seven-day records were returned, usable records declined to 60 percent by day seven. Consequently, Gersovitz et al. (1978) have concluded that the validity of food intake may be compromised by using the record for more than four day's duration.

The success of the dietary recall method depends on the subject's memory, his ability to convey estimations of quantities to the interviewer, his degree of motivation, and the persistence of the interviewer. However, memory is the major limitation associated with the recall method. The limitations associated with the dietary recall would lead one to question the validity of this method for measuring usual food intake.

There are definite problems associated with the subject's inability to recall and/or estimate certain portion sizes. Acheson et al. (1980) indicated that the recall method underestimated food intake in 79 of 86 occassions. The discrepancy between the recall and record showed that subjects in responding to the recall method omitted one or more complete food items and/or had the tendency to underestimate serving portions. Several researchers (Linusson, Sanjur & Ericson, 1974; Madden, Goodman & Guthrie, 1976; Gersovitz, Madden & Wright, 1978) reported that through regression analysis, the 24-hour recall has a tendency to overestimate low food intakes and underestimate high food intakes. Linusson et al. (1974) concluded that the 24-hour recall may not be a good predictor of actual food consumption. Gersovitz et al. (1978) further concluded that the recall method may fail to detect actual differences in food intake between groups since there is a downward bias in the number of subjects with extremely high or extremely low food intakes.

Representation of usual food intake is difficult to measure due to the intraindividual variation (biological variability) associated with food consumption from day to day, from week to week, and from season to season. Holidays, weekends, travel, and sickness may all affect the food patterns of an individual. Bazzarre et al. (1978) reported that for an individual, a one day 24-hour recall may under or overestimate usual food intake by 20-50 percent. The reliability of the 24-hour recall may be improved by increasing the number of days of data collection or the number of reported interviews in a population.

Limitations associated with the 24-hour recall may be minimized through various procedures. The interviewer may enhance the recall by beginning with the most recent meal consumed by the respondent. The subject's ability to estimate portion size may also be enhanced through the use of food models, glasses, bowls, and spoons of various sizes (Committee on Food Consumption Patterns). However, it should be noted that food models may influence the subject's reports of foods that they have not actually consumed (Simko, Cowell & Gilbride, 1984). Beaudoin and Mayer (1956) found that the more persistent an interviewer questioned obese women about their food consumption, the higher food intake became.

The primary advantage of the 24-hour recall is a higher response rate due to a light respondent burden and subjects are less likely to change their usual food patterns. The recall method is easy and quick to administer in large population studies. Furthermore, the recall is more cost effective than other dietary methodologies.

There are definite advantages and limitations associated with each method for collecting food intake. In the case of an energy balance study, the researcher must select a method that will maximize the accuracy of food intake measurement; while s/he must also minimize the limitations associated with that particular method. Weighed food records through the analysis of duplicate food samples by bomb calorimetry is the ideal method for collecting food intake during an energy balance study. However, there are major limitations associated with the use of a weighed food record in a metabolic setting. The costs for qualified staff and equipment and burden placed upon the subject (atypical living condition) may exceed available resources to conduct the study, and the typical eating and exercise patterns of each subject may be altered during this time period.

An alternative to the weighed record is the food record by household measures. Although the use of household measures to record food intake is not as accurate in the measurement of food intake, the record by household measurements may be used with a much larger population, requires less qualified staff, and less expense per subject. Consequently, in a large population, food records by household measures provide for a much more practical means for collecting food intake.

Energy Expenditure

There are few practical methods of accurately quantifying habitual physical activity (Montoye & Taylor, 1984). Habitual energy expenditure varies from one minute to the next, from day to day, and from year to year. The intraindividual variation in physical activity is a major reason valid and reliable methods for estimating energy expenditure have not been developed.

Energy expenditure is a continuous and variable function which is dependent upon the nature and intensity of the activity, environmental conditions, previous exercise, body composition and the amount of time following a meal. Exhaustive exercise may elevate metabolic rate for 12 to 24 hours following exertion (Lamb, 1984). Energy expenditure increases in a cold environment as well as in a hot and humid environment (Brooks, 1984). Resting metabolic rate is 10 to 35 percent greater following a meal as compared to the postabsorptive state. Energy expenditure during exercise following a meal is increased by 10 percent as compared to energy expenditure during similar exercise while fasting (Zahorska-Markiewicz, 1980).

There have been numerous attempts to accurately quantify energy expenditure including: (a) questionnaires and questionnaire-interview techniques (Montoye, 1971; Taylor, Coffey, Berra, Iaffaldano, Casey & Haskell, 1984; Yaskin, 1967); (b) pedometers (Gayle, Montoye & Philpot, 1977; Kemper & Verscheuer, 1977; Sarvais & Binkhorst, 1977); (c) accelerometers (Montoye, Washburn, Servais, Webster & Montoye, 1984); (d) heart rate response (Dauncy & James, 1979; Payne, Wheeler & Salvosa, 1971; Saris, Snel, Baecke, Waesberghe & Binkhorst, 1977); and (e) formal daily records (Bouchard, Tremblay, Leblanc, Lortie, Savard & Theriault, 1983). Although many researchers have attempted to successfully measure energy expenditure, there are numerous methodological problems associated with the measurement of habitual physical activity.

Questionnaires (Shapiro, Weinblatt, Frank & Sager, 1965; Yasin, 1967) and questionnaire-interview techniques (Montoye, 1971; Reiff, Montoye, Remington, Napier, Metzner & Epstein, 1967; Taylor, Jacobs, Schucker, Knudsen, Leon & Devacker, 1978) have been developed for population studies to measure habitual physical activity. Researchers (Montoye, 1971; Reiff et al., 1967) in the late 1960's and early 1970's attempted to validate the questionnaire and questionnaire-interview techniques for measuring energy expenditure; unfortunately, many of the standards for validation (food intake, body composition, and physical work capacity) were also unsatisfactory standards on which to base measures of physical activity. Validation of the

Techumseh questionnaire was determined by comparing caloric intake to energy expenditure as determined by the instrument developed by Montoye (1971) and Reiff (1967). Acheson et al. (1980) reported that caloric intake may be underestimated by 21 to 33 percent depending on the type of questionnaire used. The successful validation of questionnaire-interview techniques will depend upon an accurate standard for the measurement of physical activity.

Taylor et al. (1984) recently validated a seven-day activity and self-report as compared to the direct measure of physical activity (Vitalog^{TM}). The Vitalog^{TM} is a solid state minicomputer which measures continuous heart rate and motion. The Vitalog^{TM} was used during the same seven day period that the activity and self report were conducted. Energy expenditure for those subjects wearing the Vitalog^{TM} averaged 38.5 kcal/kg/day compared to 37.7 kcal/kg/day for the recall and 39.6 kcal/kg/day for the self-report. The authors concluded that the seven-day activity recall accurately measured energy expenditure.

Pedometers have been developed to measure the distance an individual walks or runs. The pedometer is a mechanical device that is typicaly worn on the waist and operates by the vertical movement of a lever each time the food strikes the ground. There are, however, a number of limitations associated with the validity and reliability of the pedometer for measuring habitual physical activity.

Gayle et al., (1977) identified a number of limitations that are associated with the pedometer for measuring habitual physical activity while subjects exercised on a treadmill. Two different brands of pedometers had a ± 5 percent and ± 13 percent error rate, respectively. The same pedometer worn by two different individuals recorded two distinct readings. Kemper and Versher (1977), Saris and Binkhorst (1977). Washburn, Chin and Montoye (1980) indicated that the pedometer underestimates distance traveled while walking and overestimates distance traveled while running. Gayle et al. (1977) concluded that the same pedometer recorded two different distances when it was worn on each side of the hip, which was attributed to one foot striking the ground harder than the other foot during walking and running activities. Finally, the pedometer will not measure increased energy expenditure associated with activities while the trunk is stationary (sitting, driving, cycling). Due to the previous limitations, the pedometer does not appear to provide a valid measure of daily energy expenditure.

The accelerometer was recently developed for measuring energy expenditure. The accelerometer measures energy expenditure by monitoring the vertical acceleration and deceleration of the body (Wong, 1981). The accelerometer operates on the principle that the integral of the absolute value of the acceleration divided by time correlates with oxygen consumption measurements (Montoye et al., 1984). Servais, Webster and Montoye (1984) have designed an accelerometer with a digital output that measures 11 X 6 X 2.5 cm in size. Therefore, the accelerometer's small size, weight, and convenient monitoring system provides a practical means of estimating energy expenditure without interfering with the subject's daily activities.

Although the accelerometer appears to be a promising instrument for measuring habitual physical activity, conclusive validation, and reliability studies are still needed. Montoye, Washburn, Servais, Ertl, Webster and Nagle (1983) reported that the reproducibility of the accelerometer was high (r=0.94) as compared to the measurement of oxygen consumption for four subjects performing 14 different activities. However, the accelerometer, which uses only a single calibration curve, fails to accurately record energy expenditure as compared to the measure of oxygen consumption observed for a wide range of activities (Servais et al., 1984). Further studies are necessary to determine if additional calibration curves are needed for measuring oxygen consumption over a wide range of activities in a free-living population.

Several factors limit the usefulness of the accelerometer for measuring energy expenditure. These factors include the inability of the accelerometer to measure energy expenditure while the trunk of the body is stationary (driving, cycling) or when subjects are involved in high force activities with small displacements such as weight lifting, or isometric exercises. Another limitation of the accelerometer is that the energy expenditure required to ascend an incline is not recorded (Servais et al., 1984). The accelerometer also recorded identical energy expenditures, whether the subject was running on a flat surface or running up an incline.

The limitations associated with the accelerometer may severely limit the use of the accelerometer for populations that are relatively sedentary. Furthermore, more conclusive research is needed to elucidate the validity of energy expenditure recorded by the accelerometer before it may be used to measure habitual physical activity.

The heart rate technique provides a means of continuously monitoring total energy expenditure. Researchers have demonstrated that heart rate is both linear and highly correlated at levels of expenditure above the basal level and below those levels associated with very hard work (Poulsen & Asmussen, 1962; Webster, 1967). However, the heart rate technique is not without limitations. Heart rate may be affected by factors other than basal metabolic rate including body position, activity level, fitness level, site of muscular activity, environmental conditions, state of hydration, diet, and emotional state (Andrews, 1971; Berg, 1971; Bradfield, 1971; Lundgren, 1946; Montoye et al., 1984).

At rest, heart rate is primarily a function of physical condition. Trained individuals have a lower resting heart rate than untrained individuals; while females have a higher heart rate during exercise than males (Montoye, 1975). At rest, there is large subject-to-subject variation associated with the heart rate technique for measuring energy expenditure.

The site of muscular contraction affects hemodynamics and thus, heart rate. During heavy exercise involving the arms only, the heart rate increases disproportionately to the amount of energy expenditure. Heavy arm exercise increases heart rate to a slightly greater extent than for both arm and leg exercise (Durnin & Namyslowski, 1958). During high force exercise (isometrics, weight training), heart rate increases to a greater level than actual energy expenditure (Hanson & Maggio, 1960).

Extreme environmental conditions affect heart rate. High environmental temperatures increase heart rate above actual energy expenditure (Brooks, 1984). Dehydration due to high ambient temperatures and humidity and/or a limited fluid intake will elevate heart rate (Lundgren, 1946). Diet and emotional state also affect heart rate. Heart rate may increase by 10 to 35 percent following a meal

(Zahorska-Markiewicz, 1980). Although emotions will affect heart rate for a period of time, it is believed that brief emotional excitment over the course of a 24-hour period will not significantly affect the measurement of energy expenditure.

Due to the intra and interindividual variations in heart rate response, a method needed to be developed to identify a direct relationship between heart rate and energy expenditure. In an effort to identify a direct relationship between heart rate and energy expenditure, oxygen uptake calibration curves were developed (Andrews, 1971; Bradfield, 1971). The calibration curve provides a means of converting field measurements of heart rate into oxygen uptake values. The oxygen uptake calibration curve is based upon two premises: (a) there is a linear relationship between heart rate and oxygen consumption above the basal level and below the level achieved for maximal exercise; and (b) oxygen consumption is the standard used to measure energy expenditure (Martitz, Morrison, Peter, Strydon & Wyndam, 1961).

Andrews (1971) suggested that a single regression equation may be developed for each category of activity to minimize intersubject differences between heart rate and oxygen uptake. Four categories of activities (standing, sitting, bending over, and walking) were used to account for differences in blood distribution or circulation.

Therefore, each regression equation would be applicable to a specific category of activities which have similar circulatory patterns. Thus, each category of activities had a similar relationship between net heart rate and net energy expenditure. In addition to the continuous monitoring of heart rate, each subject recorded the time periods within which each category of activity was performed. Thus, the time period for each category of activity could then be matched with the corresponding heart rate to determine net energy expenditure.

Several heart rate techniques for measuring energy expenditure have been developed including the SAMI, and the Vitalog™. The development of the SAMI allows one to measure energy expenditure without the inhibition caused by respiratory equipment, or observers. Practically no cooperation is required by the subject; while heart rate can be monitored continuously and inconspicuously without significantly burdening the subject (Bradfield, Bradfield & Payne, 1971). The primary limitation of the SAMI heart rate technique is that sources of error are introduced by the time estimation for the various activities and disturbances in the subjects daily routine due to diary entries. Even if the activity recorded by the subject corresponds to actual activity levels, the intensity of exercise is difficult to accurately quantify (Heywood, Rur & Latham, 1971).

The development of solid-state electronics now allows the measurement of both activity and heart rate making it possible to compare activity levels to corresponding heart rates (Taylor, Kraemer & Bragg, 1982). The Vitalog^{TM} uses three chest electrodes to determine heart rate through an R-R wave detection program. The device measures 4 X 8 X 12 cm and weighs 0.5 kg.

The primary advantage of the Vitalog^{TM} compared to telemetry and the SAMI, is that subjects do not need to record daily activities in order to compare activity levels to corresponding heart rates. However, as in the case of the SAMI, a regression equation must also be developed for each subject who will be wearing the Vitalog^{TM}. Therefore, each subject must undergo a graded maximal exercise text to develop a heart rate-energy expenditure relationship at moderate, hard, and very hard exercise intensities (Taylor et al., 1982).

The heart rate technique provides a valid measure of habitual physical activity; however, there are a number of factors that limit the practicality of this method. The development of heart rate regression equations for each individual can be very time consuming. The heart rate technique cannot be easily used for large population studies. Moreover, the heart rate technique may alter subjects' daily exercise patterns. Consequently, alternative methods must be used to measure habitual energy expenditure in relatively large populations.

Diary methods have been developed for measuring habitual physical activity patterns in population studies (Acheson, Campbell, Edholm, Miller & Stock, 1980; Bouchard, Tremblay, Leblanc, Lortie, Savard & Theriault, 1983). A code is generally necessary; while the use of energy cost tables are necessary to express energy expenditure in calories. Diary methods for monitoring energy expenditure usually require a great deal of cooperation from the subject (Montoye et al., 1984).

Bouchard et al. (1983) designed a three-day diary to descriminate along the continuum of daily energy expenditure. The diary information provided a means of classifying subjects by rank order on the basis of their average daily energy expenditure. The reproducibility for energy expenditure was (r=0.96) through the use of a three-day diary. The diary is based on the median energy costs for relevant activities for each of the 96 15-minute periods. Since a median energy cost is used for each of the nine categories, the diary method may not be sufficiently valid for energy balance studies. Consequently, the diary may provide a relative rank ordering of energy expenditure for subjects but not an absolute measurement. As compared to other methods such as frequency questionnaires and recalls, histories of physical activity patterns, the diary provides the most quantitative estimate of actual daily energy expenditure. The diary form also has the advantage of measuring energy expenditure in free living populations during their usual range of daily activities. Measurements using special equipment such as pedometers, accelerometers, and vitalometers are thought to bias respondents usual activity patterns since these subjects report a greater compulsion to exercise more, and to exercise at a higher intensity of effort than usual. Awareness of the need to record or recall activities may also predispose individuals to be more physically active as well.

Although the diary designed by Bouchard et al. (1983) may be convenient for large population studies, there are several limitations to this method. The diary method requires a great deal of cooperation from subjects which may limit adherance. Subjects may not complete the diary at 15 minute intervals, but instead subjects may complete the diary all at once. Therefore, the reliability and adherance rates may be reduced by the diary method. Further research needs to be done to replicate the study conducted by Bouchard et al. (1983).

There have been numerous procedures developed to measure habitual physical activity, and each method has it's own advantages and limitations. The heart rate technique may be the most accurate method for measuring energy expenditure in a free-living population; however, there are a number of limitations to using the heart rate device with a relatively large population. The diary recall and questionnaire-interview techniques do not continuously monitor energy expenditure, but these methods may provide a more practical (time, expense, cooperation) means for measuring energy expenditure in a relatively large population.

Summary

This review of the literature indicates that there are no known studies that have evaluated energy balance in endurance athletes in training. Evidence suggests that during mild to moderate exercise, lean subjects maintain energy balance, while obese subjects have a small negative energy balance. At present, there is no evidence to indicate whether endurance athletes are able to consume sufficient calories to maintain energy balance. If endurance athletes are unable to maintain energy balance, at what level will energy expenditure exceed the athlete's ability to consume sufficient calories to maintain energy balance.

This review of the literature also suggests that energy expenditure at rest and during exercise may be reduced following chronic food restriction. However, it has not been determined whether endurance athletes whose high energy expenditure exceeds his/her ability to consume a sufficient amount of calories (rather than a reduction in caloric intake to create an energy deficit) brings into play an adaptive mechanism which allows for the conservation of energy at rest and during exercise, thus affecting energy balance. Furthermore, if endurance athletes do conserve energy at rest and during exercise when challenged by a widening gap between actual needs of intake, at what critical percent body fat will this occur? It would appear that a greater energy conservation would occur with a greater energy deficit as one approaches his/her critical percent body fat a decline in performance may be a protective mechanism. If energy conservation does occur at some point in negative energy balance among endurance athletes, this imbalance would further complicate the measurement of energy balance through indirect measure of energy intake, and energy expenditure.

CHAPTER III

METHODOLOGY

Subjects

Subjects were recruited from a triathlon club formed at UNC-G. A flier that was used to advertise the first organizational meeting of the club is included in Appendix A. Fliers and announcements were distributed through the UNC-G Office for Intramurals and Club Sports, the Greensboro Running Club, public service announcements, local bike clubs, spas, fitness centers, and a mailing list from the High Point Youth Unlimited Triathlon. All club members were used as the pool of individuals from which the research subjects were selected. Subjects were male endurance athletes 15 to 52 years of age. The target research population consisted of two groups of endurance athletes. Based on percent body fat ranked in descending order at week 0, the first group consisted of those subjects in the upper tertile while the second group consisted of those subects in the lower tertile. Each subject signed a consent form prior to his participation in this research project. Any subject over the age of 35 obtained a physician's clearance prior to participation. Any individual who reported having a medical history of CHD, hypertension, or diabetes was screened from the study (Appendix B).

Exercise

Recommended training protocols were developed for each of the triathlon events (swimming, cycling, running) (Appencix C). Based on initial fitness and training levels, four training programs were developed for each event (level I, II, III, master's). Each subject was given a log book to record training milage. Log books were reviewed by the researchers periodically to assess training progress. Subjects often called the researchers for advice regarding their training program. Workshops and clinics were held three times per month to maintain subject morale and to provide training information.

Food and Nutrient Intake

Food intake was collected for a one week period using a seven-day food record (household measures) at week 0. The researcher was trained to administer the protocol for a seven-day food record for each subject (Appendix D). Each subject's seven-day food record was evaluated for completeness prior to the computer nutrient analysis. Each subject's seven-day nutrient intake was then analyzed by the Nutranal 3.1 computer software program.

Energy Expenditure

Energy expenditure was monitored through the use of a seven-day activity record (diary) at week 0. The protocol for the collection of energy expenditure was similar to the methods outlined by Bouchard et al. (1983). Each day is divided into 15-minute periods (96 periods/day). Participants entered a categorical value ranging from one (low energy expenditure) to nine (high energy expenditure) corresponding to the dominant activity for each 15-minute period (Appendix E).

Anthropometric Measurements

Height (cm) and weight (kg) was measured using the same Detecto™ beam scale. The Durnin et al. (1974) formula was used to determine body fat based on the sum of four skinfold measurements (triceps, biceps, suprailiac, subscapular). A conversion table by Durnin et al. (1974) was used to convert the sum of four skinfolds to percent body fat. Percent body fat was also assessed by hydrostatic weighing, utilizing the procedures described by Sinning (1975). An effort was made so that the same technician measured and recorded each subjects' anthropometric measurements for both data collection periods.

Physical Work Capacity

Physical work capacity was determined by a submaximal bicycle ergometer test at weeks 0 and 24 (Astrand et al., 1954). A submaximal bicycle ergometer test may under or overestimate one's maximal oxygen consumption by 10 percent or greater (Nagle, 1973). Therefore, the reliability of the submaximal bicycle ergometer test is not entirely satisfactory for predicting maximal oxygen consumption in individuals. However, the submaximal bicycle ergometer test is a practical method of assessing maximal oxygen consumption in a sample rather than in individuals.

The 12-minute run was used to assess each participant's fitness level at weeks 0 and 24. The 12-minute run was used since it is a simple, inexpensive measure of aerobic fitness. The 12-minute run also provides a tangible means for monitoring a participant's improvement. A participant may relate more cognitively to an increase in running distance during a given time interval than to an increase in oxygen consumption capacity. The 12-minute run correlates highly ($r=0.94$) with maximum oxygen consumption while exercising on the treadmill (Cooper, 1980).

Statistical Analyses

The SAS (Statistical Analysis Systems) package was used for the statistical analysis of each hypotheses. Although several variables were not normally distributed, the use of either parametric or nonparametric statistics did not affect the conclusions drawn from this study. The age for the upper and lower tertiles were not significantly different and had no effect on the conclusion of this study. Therefore, parametric statistics were used to test each hypotheses. Means and standard deviation were calculated for each variable. For each of the following hypotheses a p-value of less than or equal to 0.05 was considered significant.

Hypothesis 1

Subjects were selected on the basis of percent body fat as determined by the formula of Durnin et al. (1974). Subjects were categorized as either: (a) the upper tertile; or (b) the lower tertile. Analysis of variance was used to determine if there was a significant difference between the upper tertile and the lower tertile for energy intake, energy balance, work performance using the bicycle ergometer protocol, and work performance during the 12-minute run.

Hypothesis 2

For those subjects who lost weight from week 0 to week 24, FFW loss as a percent of TBW was determined for both the lower tertile and the upper tertile. Analysis of variance was used to determine whether there was a significant difference in FFW loss as a percent of TBW between the lower tertile and the upper tertile.

Hypothesis 3

A Pearson's Correlation Coefficient was used to determine whether there was any association between energy balance (independent variable) at week 0 and a loss of FFW as a percent of TBW (dependent variable) at week 0 in the lower tertile and the upper tertile.

Hypotheses 4 and 5

For those subjects who lost weight and lost FFW as a percent of TBW from week 0 to week 24, analysis of variance was used to determine whether there was a significant difference in work performance from week 0 to week 24 while exercising on the bicycle ergometer (12-minute run test).

CHAPTER IV

RESULTS

The results of this dissertation research are presented in Tables 4 through 9. The results of the descriptive data on initial height, body weight, FW, and percent body fat of the lower tertile and the upper tertile at week 0 are presented in Table 4; while the means and standard deviations for energy intake, energy expenditure, and energy balance for the lower tertile and the upper tertile at week 0 are presented in Table 5. Measures of physical work capacity using a bicycle ergometer test and the 12-minute run test at week 0 are presented in Table 6. Measures of physical work capacity at week 24 are presented in Table 7. Differences in work performance from week 0 to 24 for the upper and lower tertile may be observed in Table 8. Differences in FFW loss as a percent of TBW for the lower tertile and the upper tertile from week 0 to week 24 are presented in the text. Finally, the results of the difference in physical work capacity from week 0 to week 24 among those subjects who had a decrease in FFW as a percent of total body are presented in Table 9. The results for testing each of the hypotheses will be presented in the narrative description for the results as presented in Tables 4 to 9.

Subjects

Thirty-two male subjects had data available at week 0 and week 24. Based on percent body fat at week 0, all male endurance subjects were separated into tertiles. The upper tertile (mean age 33.3 ± 8.8 years) consisted of those subjects (n=11) with a mean percent body fat of 15.4 ± 2.8 percent, and a range of 12.6 to 20.7 percent. The lower tertile (mean age 27.4 ± 4.1 years) consisted of those subjects (n=11) with a mean percent body fat of 7.4 ± 1.4 percent and a range of 4.8 to 8.6 percent (Table 4). The mean height for the lower tertile was 178.5 ± 7.2 cm and 178.6 ± 4.5 cm for the upper tertile. The upper tertile had a higher mean body weight (75.9 ± 8.5 kg) and a higher mean FW (11.7 ± 2.4 kg) than the lower tertile who had a mean body weight of 69.2 ± 6.8 kg and a mean FW of 5.1 ± 1.2 kg. There was no significant difference between the upper and lower tertile for age and height. Total body weight loss from week 0 to 24 was nonsignificant for both the upper (-2.6 ± 6.0 kg) and lower (-0.2 ± 2.4 kg) tertiles; while percent body fat loss was also nonsignificant for the upper (-1.1 ± 1.8 percent) and the lower (0.4 ± 1.7 percent) tertiles.

Table 4

Body Weight, Percent Body Fat, and Fat Weight in the Lower Tertile and the Upper Tertile at Week 0 (Means and Standard Deviations).

	Lower Tertile (n=11)	Upper Tertile (n=11)
Height (cm)	178.5 ± 7.2	178.6 ± 4.5
Body Weight (kg)	69.2 ± 6.8	75.9 ± 8.5
Fat Weight (kg)	5.1 ± 1.2	11.7 ± 2.4
Body Fat (%)	7.4 ± 1.4	15.4 ± 2.8

Fat Free Weight

There was no significant change in FFW as a percent of TBW for the lower tertile (0.0 ± 0.3) and the upper tertile (0.0 ± 0) from week 0 to 24 (Hypothesis 2). The range for the difference in FFW as a percent of TBW was -2.0 to 2.9 percent.

Energy Balance

Means and standard deviations for energy intake, energy expenditure, and energy balance at week 0 for the lower tertile and the upper tertile are presented in Table 5. Mean energy intake (kcal/day) was significantly higher ($p < .01$) among the lower tertile (3208 ± 832 kcal) than among the upper tertile (2204 ± 751 kcal). Mean energy expenditure was also lower in the lower tertile (3304 ± 466 kcal) than among the upper tertile (3676 ± 679 kcal). Negative energy balance was recorded for both the lower tertile and the upper tertile. Mean energy balance (kcal/day) was significantly lower ($p < .02$) among the lower tertile (-294 ± 781 kcal) than among the upper tertile (-1472 ± 1131 kcal). Thus, energy intake and energy balance were not significantly different between the upper and lower tertiles (Hypotheses 1a and 1b). At week 0, there was no association between energy balance and FFW (Hypothesis 3). Energy intake, energy expenditure, and energy balance were not evaluated at week 24 due to the small number of food records returned during this time period.

Table 5

Energy Intake, Energy Expenditure, and Energy Balance for the Lower Tertile and the Upper Tertile at Week 0 (Means and Standard Deviations).

	Lower Tertile (n)	Upper Tertile (n)	P-Value
Energy Intake[a] (kcal/day)	3208 ± 832 (10)	2204 ± 751 (10)	0.01
Energy Expenditure[a] (kcal/day)	3304 ± 466 (9)	3676 ± 679 (10)	
Energy Balance[a] (kcal/day)	-294 ± 781 (9)	-1472 ± 1131 (10)	0.02

[a]Numbers are based on the seven-day average.

Physical Work Capacity

Measures of physical work capacity at week 0 for the lower tertile and the upper tertile are presented in Table 6. Maximal oxygen consumption in liters per minute while exercising on a bicycle ergometer was higher among the lower tertile (3.7 ± 0.6) than the upper tertile (3.3 ± 0.7). However, oxygen consumption in milliliters per kg body weight per minute was significantly higher ($p < .006$) among the lower tertile (52.7 ± 10.8) than the upper tertile (40.4 ± 7.2). The distance traveled in miles during the 12-minute run was significantly higher ($p < .002$) among the lower tertile (2.0 ± 0.1) as compared to the upper tertile (1.8 ± 0.1). Thus, physical work capacity (ml O_2/kg/min; and distance run) was higher in the lower tertile than the upper tertile (Hypothesis 1c and 1d).

Table 6

Measures of Physical Work Capacity in the Lower Tertile and the Upper Tertile at Week 0 (Means and Standard Deviations).

	Lower Tertile (n)	Upper Tertile (n)	P-Value
Bicycle Ergometer			
VO_2 (l/min)	3.7 ± 0.6 (11)	3.3 ± 0.7 (10)	0.181
VO_2 (ml O_2/kg/min)	52.7 ± 10.8 (11)	40.4 ± 7.2 (11)	0.006
12-Minute Run (miles)	2.0 ± 0.1	1.8 ± 0.1	0.002

At week 24, there was no significant difference in maximal oxygen consumption (l/min) between the upper and lower tertiles (Table 7). However, oxygen uptake (ml 0_2/kg/min) remained significantly higher ($p < 0.026$) at week 24 for the lower tertile (56.0 ± 10.0) than for the upper tertile (45.7 ± 4.5). The lower tertile ran a significantly greater distance (2.2 ± 0.1; $p < .005$) in miles during the 12-minute run as compared to the upper tertile (1.8 ± 0.2). Thus, the lower tertile ran 0.2 miles more than the upper tertile at week 0, but they ran 0.4 miles more at week 24.

Table 7

Measures of Physical Work Capacity in the Lower Tertile and the Upper Tertile at Week 24 (Means and Standard Deviations).

	Lower Tertile (n)	Upper Tertile (n)	P-Value
Bicycle Ergometer			
VO_2(l/min)	4.0 ± 0.4 (9)	3.8 ± 0.7 (6)	.555
VO_2(ml 0_2/kg/min)	56.0 ± 10.0 (9)	45.7 ± 4.5 (7)	.026
12-Minute Run (miles)	2.2 ± 0.1 (6)	1.8 ± 0.2 (6)	.005

There was no significant change in physical work capacity from week 0 to 24 for both the upper and lower tertile except that oxygen uptake (l/min) was significantly higher ($p < 0.04$) for the upper tertile (Table 8). From week 0 to 24, oxygen uptake (5.1 ± 6.2 ml O_2/kg/min; $p < 0.074$) for the upper tertile approached significance; while the distance run during the 12-minute run (0.1 ± 0.1 miles, $p < 0.085$) also approached significance.

Table 8

Differences in Work Performance from Week 0 to 24 for the Upper and Lower Tertiles.

	(n)	Difference Score	P-Value
Bicycle Ergometer			
VO_2 (l/min)			
Upper Tertile	6	0.2 ± 0.2	.040
Lower Tertile	9	0.2 ± 0.6	.200
VO_2 (ml O_2/kg/min)			
Upper Tertile	7	5.1 ± 6.2	.074
Lower Tertile	9	3.2 ± 8.8	.311
12-Minute Run (miles)			
Upper Tertile	6	0.1 ± 0.1	.256
Lower Tertile	6	0.1 ± 0.1	.085

Difference scores in physical work performance from week 0 to week 24 among those subjects who lost FFW (n=12) as a percent of TBW from week 0 to week 24 are presented in

Table 9. A loss of FFW as a percent of TBW had no significant effect on physical work capacity (Hypotheses 4 and 5). Measures of O_2 in l/min using the bicycle ergometer test increased 0.4 ± 0.6 ($p < 0.06$) from week 0 to week 24. Measures of VO_2 (ml O_2/kg/min) using the bicycle ergometer protocol increased 4.5 ± 8.7. The distance traveled in miles during the 12-minute run decreased (-0.1 ± 0.4 miles) from week 0 to week 24.

Table 9

Difference in Work Performance From Week 0 to 24 Among Subjects Who Lost Fat Free Weight as a Percent of Total Body Weight

	n	Difference Score	P-Value
Bicycle Ergometer			
VO_2 (l/min)	12	0.4 ± 0.6	0.06
VO_2 (ml O_2/kg/min)	12	4.5 ± 8.7	0.10
12-Minute Run (miles)	14	-0.1 ± 0.4	0.16

Summary

Energy intake was higher for the lower tertile; while the upper tertile had a greater negative energy balance than the lower tertile. The lower tertile had a significantly greater physical work capacity (ml/kg/min) than the upper tertile at weeks 0 and 24. Physical work capacity (l/min) increased significantly from week 0 to 24 only for the upper tertile. There was no significant difference in FFW loss as a percent of TBW for week 0 to 24 among the upper and lower tertiles. Physical work capacity (12-minute run) decreased slightly among those subjects who had a decrease in FFW as a percent of TBW.

CHAPTER V

DISCUSSION

The results and findings of this study are based on energy intake, energy balance, physical work capacity, difference in FFW as a percent of TBW, and differences in physical work capacity among those subjects who have a decrease in FFW as a percent of TBW. The results for each variable will be discussed and compared to the current literature. Recommendations for further research will also be addressed to further clarify the effects of physical activity on energy intake, energy expenditure, alterations in body composition, and the effect of FFW loss on physical work capacity.

Fat Free Weight

Differences in FFW loss as a percent of TBW were not significantly different between the lower tertile and the upper tertile. A number of factors may account for the small differences in FFW as a percent of TBW from week 0 to 24. The intensity, frequency, and duration of exercise may not have been sufficient to decrease FFW. A relatively short (i.e. eight weeks), more intensive endurance training program may result in a greater loss of FFW as a percent of

TBW as compared to a long term (24 weeks) moderately intensive endurance training program. Subjects placed on a short term intensive endurance training program may have a high frequency of large energy deficits whereby body protein stores are utilized to assist in the maintenance of energy needs. In the case of successive large energy deficits, the body's protein stores are compromised to such an extent as to reduce FFW. Whereas, weight loss that occurs over an extended period of time may prevent large energy deficits and thus spare protein stores and maintain FFW.

It would appear that energy intake nearly matched energy expenditure over the course of the 24-week period which might account for the small decrease in TBW for the lower tertile (0.2 kg). Energy expenditure may have exceeded energy intake over the 24-week period since the upper tertile had a decrease in TBW of 2.6 kg. Forbes (1985) indicates that overfeeding (positive energy balance) increases lean body mass and underfeeding (negative energy balance) diminishes lean body mass. In this study, relatively small change in TBW along with regular exercise may have prevented large losses of FFW. However, to further complicate this issue (Lammert et al., 1982) reported that subjects in negative energy balance have a decrease in BMR and utilize energy more efficiently during exercise. Therefore, subjects who were in negative energy balance may have a decrease in BMR and utilize energy during exercise more efficiently which may effectively result in the maintenance of energy balance. Theoretically, it is possible that a greater loss of TBW and FFW could have occurred (greater than actual losses), if physiological adaptions did not occur to assist in the maintenance of energy balance.

Genetic predisposition to alterations in body composition as a result of exercise may confound the small differences in FFW loss as a percent of TBW among the lower tertile and the upper tertile. Each individual may have a critical percent body fat where a greater proportion of FFW loss per kg of weight loss may occur than at a higher percent body fat. Subjects with a large number of adipocytes may have a more difficult time reaching a critical percent body fat and if he reaches a critical percent body fat, a greater proportion of FFW loss per kg of weight loss may occur as compared to individuals with a lower number of adipocytes.

The two-component system (hydrostatic weighing, skinfold measurments) for measuring body composition may not have been sensitive enough to detect actual differences in FFW among the lower tertile and the upper tertile. Present evidence indicates that the assumptions underlying the hydrostatic weighing procedure may not be as appropriate as once assumed (Wilmore, 1980). Variability in FFW determined by densitometry of white college-aged males is believed to be ±3 percent; however, the variability in FFW among athletes has yet to be measured (Lohman, 1984). Moreover, hydrostatic weighing and skinfold measurements cannot determine the relative proportion of each constituent of FFW. Pollock et al. (1978) reported that exercise may induce muscle hypertrophy, increase bone density, and increase blood volume. Consequently, further research needs to be conducted to develop methods that accurately assess alterations in the components of FFW.

Physical Work Capacity

Physical work capacity was significantly higher in the lower tertile than in the upper tertile at week 0; however, there was no significant difference in physical work capacity among the lower tertile and the upper tertile when body weight was not considered. Although the lower tertile were more aerobically fit than the upper tertile, the upper tertile had a greater body weight and FFW that may account for the nearly similar VO_2 (l/min) for the lower tertile (3.7 ± 0.6) and the upper tertile (3.3 ± 0.7). The difference in VO_2 (ml O_2/kg/min) and differences in the 12-minute run among the lower tertile and the upper tertile may be attributed to the lower tertile more extensive training background and a lower percent body fat.

From week 0 to 24, there was a slight increase in physical work capacity for both the upper and lower tertiles. The relative difference in physical work capacity between the upper and lower tertiles remained approximately the same at week 0 and at week 24. The nonsignificant increase in physical work capacity among the lower tertile may be due to an initially high fitness level at week 0.

Effect of Fat Free Weight on Physical Work Capacity

Small decreases in FFW had little effect on physical work capacity in male endurance athletes during the 24-week endurance training program. A number of factors may account for the nonsignificant differences in physical work capacity among those subjects who lost FFW from week 0 to 24. The intensity, frequency, and duration of exercise may not have been sufficient to decrease FFW to such an extent as to reduce physical work capacity. Furthermore, subjects with a relatively low fitness level at baseline were likely to have an increase in FFW and an increase in physical work capacity.

The intensity and duration of exercise should be considered in evaluating the effects of a loss of FFW on alterations in physical work capacity. The distance traveled (miles) during the 12-minute run (maximal test) decreased slightly from week 0 to 24 (i.e. 0.1 miles), whereas, oxygen consumption increased from week 0 to 24 with the submaximal bicycle ergometer protocol. A small decrease in physical work capacity during maximal exercise may cause one to question how small losses of FFW affect different measures of performance (i.e. high intensity maximum effort performance vs. submaximal endurance performance). Furthermore, for those subjects who lose FFW from one point in time to another, will performance during submaximal exercise to exhaustion decrease physical work capacity as opposed to submaximal exercise for a short duration.

Valid and reliable measures of FFW using the two-component system of measuring body composition severely limits a researcher's ability to predict changes in physical work capacity due to a reduction in FFW. Alterations in the constituents of FFW cannot be accounted for with the two-component method for measuring body composition. One subject may have an increase in one constituent of FFW, while another subject may have a decrease in that same component. Therefore, it is difficult to predict changes in physical work capacity due to a reduction in total FFW. A better method to evaluate the effects of a reduction in FFW on physical work capacity would be to measure each constituent of FFW. Alterations in the constituents of FFW may provide more information regarding the effect of a decrease in FFW on physical work capacity.

Measures of physical work capacity are only estimates of actual physical performance. The Astrand (1949) bicycle ergometer protocol predicts maximum oxygen consumption and has an error rate of ±10 percent. Under ideal conditions the Cooper (1980) 12-minute run correlates highly (r=.90) with oxygen consumption while exercising on a treadmill. Both the bicycle ergometer test and the Cooper 12-minute run may not have accurately predicted changes in physical work capacity from week 0 to 24.

<u>Energy Intake</u>

Energy intake was significantly higher among the lower tertile as compared to the upper tertile. Blair, Ellsworth, Haskell, Stein, Farquhar, and Wood (1981) reported that male recreational runners (41 miles per week) consumed 2959 kcal/day which was similar to the energy intake for the lower tertile (3208 kcal/day). However, energy intake for the upper tertile (2204 kcal/day) was similar to the energy intake for the sedentary control subjects (2386 kcal/day) in the study by Blair et al. (1981). Kirsch et al. (1981) reported that energy intake was 3330 kcal/day in male runners (50 miles per week) and 6308 kcal/day in male cyclists training greater than eight hours per week. Clement et al. (1982) indicated that energy intake was 3020 kcal/day in male distance runners whose training distance was seven miles per day.

Several factors may account for differences in energy intake among the lower tertile and the upper tertile. Energy intake may have been intentionally reduced by the upper tertile to promote weight loss; whereas, the lower tertile may have consciously or subconsciously increased their energy intake to maintain weight. Energy intake may be underestimated by both the lower tertile and the upper tertile. However, the upper tertile may be more likely to underestimate energy intake by omitting food items and underestimating portion sizes since they may have been attempting to lose fat by reducing caloric intake (dietary). The training histories of each group may affect energy intake. Since the lower tertile are more highly trained, and thus, are capable of expending more energy during a given unit of time, it would be expected that they would consume more calories than the upper tertile.

The validity of energy intake may be affected by the length of the food record (i.e. four-day versus seven-day), and the methodology (household measures versus weighed measures) used to measure food intake. A seven-day food record may have compromised the validity of energy intake for both the lower tertile and upper tertile. Gersovitz et al. (1978) reported that seven-day food records were returned by the more highly educated group, and that the accuracy of food records declined by the fifth, sixth and seventh days. Gersovitz et al. (1978) concluded that the validity of food intake may be compromised by using the record for more than four days duration. Van Staveren et al. (1985) reported that household measures of food intake provide an accurate estimate of food intake in a relatively large population. However, household measures may not provide as valid a measure of food intake as weighed food records considering the relatively small sample (n=10). Therefore, a weighed food record may provide a more appropriate method to accurately quantify energy intake if the subjects were willing to cooperate.

Energy Expenditure

Energy expenditure for the lower tertile (3304) was less than the energy expenditure for the upper tertile (3676). Although it may come as a surprise, the upper tertile have a 372 kcal/day greater energy expenditure than the lower tertile. Due to the limitations associated with the Bouchard et al. (1983) method for measuring energy expenditure, it is difficult to accurately assess whether the lower tertile or the upper tertile had a higher caloric expenditure.

Several inherent factors may limit the Bouchard et al. (1983) method for accurately quantifying energy expenditure. The method is very subjective since the procedure requires that each subject interpret the intensity of daily activities according to the nine categories measured in MET levels. Each subject may perceive the same given activity differently and, thus, each subject may assign a different MET level to that same activity. Bouchard et al. (1983) suggested that the measurement of energy expenditure may not be as accurate for individuals or groups involved in very intensive exercise (i.e. category nine, running more than nine km/hour).

Measures of energy expenditure may be more accurate if FFW was also taken into account rather than TBW. Bray & Campfield (1975) reported that subjects with a greater FFW have a higher BMR than those subjects with the same TBW but who also have a lower FFW. However, additional adiposity cannot be totally disregarded since energy is required to carry additional fat weight. Consequently, the validity of the Bouchard et al. (1983) method for measuring energy expenditure might be improved if each subject's FFW was taken into consideration along with TBW.

Energy Balance

Both the lower tertile (-294) and the upper tertile (-1472) had a negative energy balance at week 0. Since the validity of the instrument used to measure energy expenditure is questionable, it is difficult to conclude with certainty that the upper tertile had the greater negative energy balance. Thus, further research is still needed to test the basic hypotheses of this dissertation research.

Possible Mechanisms

Obviously, if future research demonstrated that a decrease in LBM occurs among endurance athletes with low body fat, and that these changes compromise endurance performance, there would be an interest in studying the mechanisms that regulate body composition as well as the mechanisms by which such changes impair performance. Research on factors that affect energy balance among endurance athletes should include studies on the regulation of food intake, and studies that address thermoregulatory mechanisms, especially those mechanisms that may alter basal metabolism. Finally, research should evaluate changes in energy substrate availability and utilization. The latter area might include studies of changes in enzyme kinetics as well as studies that examine alterations in neurohormonal regulators of energy substrates during endurance activities of 2-3 hours duration or longer.

CHAPTER VI

SUMMARY

This dissertation research investigated the effects of an endurance training program on caloric intake, energy expenditure, FFW, and physical work capacity in the upper tertile and the lower tertile. Thirty-two male subjects who had data available at weeks 0 and 24 were separated into tertiles. The upper tertile consisted of those subjects with a mean body fat of 15.4 percent; while the lower tertile consisted of those subjects with a mean body fat of 7.4 percent. Energy expenditure was measured using a seven-day activity record. A seven-day food record was used to measure energy intake. The sum of four skinfolds was used to measure FFW at weeks 0 and 24. Physical work capacity was measured using a submaximal bicycle ergometer protocol (Astrand et al., 1954) and a 12-minute run (Cooper, 1980).

There was no significant difference in FFW loss as a percent of TBW from week 0 to 24 for the lower tertile and the upper tertile. Several factors such as the intensity of exercise, genetic predisposition to alterations in body composition, and the researcher's inability to detect small changes in body composition using the two-component method may have accounted for the small change in FFW as a percent of TBW. Although there was a decrease of 0.1 miles run during the 12-minute run from week 0 to week 24, a small decrease in FFW loss as a percent of TBW had no significant affect on physical work capacity in male endurance athletes. At week 0 there was no significant relationship between energy balance and FFW in male endurance athletes.

Energy intake at week 0 was significantly higher among the lower tertile than for the upper tertile. A negative energy balance was reported for both the lower tertile and the upper tertile. However, negative energy balance was significantly greater for the upper tertile as compared to the lower tertile. The large difference in energy balance between the lower tertile and the upper tertile is possibly due to the upper tertile attempt to reduce body fat by restricting caloric intake. Although the upper tertile had a greater negative energy balance than the lower tertile, they also had a slightly greater energy expenditure than the lower tertile.

Recommendations

Recommendations that might improve the ability to draw conclusions from this study include: (a) reduce the length of the study period from 24 weeks to 8 weeks; (b) place subjects on a more intensive endurance training program; (c) monitor each subject's training program more closely;

(d) use a weighed food record (by the researchers) whereby each subject would consume all meals at a common location; (e) use of a whole body calorimeter may provide a more accurate measure of energy expenditure at specific time periods during the study; (f) use body composition methods such as neutron activation analysis, isotopic dilution, and bone density analysis that measures each of the constituents of FFW; and (g) use a more precise measure of physical work capacity such as a maximal bicycle ergometer protocol or a maximal treadmill test.

Basic research needs to be conducted before applied research may be undertaken to evaluate the effects of an endurance training program on energy intake, energy expenditure, energy balance, alterations in FFW, and the effects of a loss of FFW as a percent of TBW on physical work capacity. Once basic research has been undertaken to perfect measures of food intake, energy expenditure, and body composition analysis, a number of studies need to be conducted to evaluate the following:

1. Energy intake, energy expenditure, and energy balance needs to be measured in subjects involved in various sporting events.

2. Is there a conservation of energy when a subject is placed in negative energy balance due to an intensive endurance training program?

3. If energy conservation does occur, when and how does it occur?

4. Is there a critical percent body fat at which point energy conservation occurs during an intensive endurance training program?

5. Is there a critical percent body fat for each individual whereby there is a greater loss of FFW as a percent of TBW than at a higher percent body fat?

6. Will a loss of FFW as a result of an endurance training program compromise physical performance?

7. With a loss of FFW over the course of an endurance training program, which constituents of FFW (water, bone, muscle) are altered to the greatest extent?

8. If one can accurately quantify alterations in FFW, which constituents of FFW have the greatest effect on physical work capacity?

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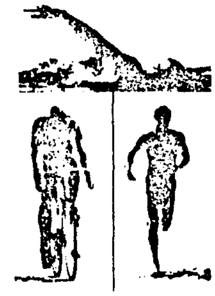
APPENDIX A

ORGANIZATIONAL FLIER



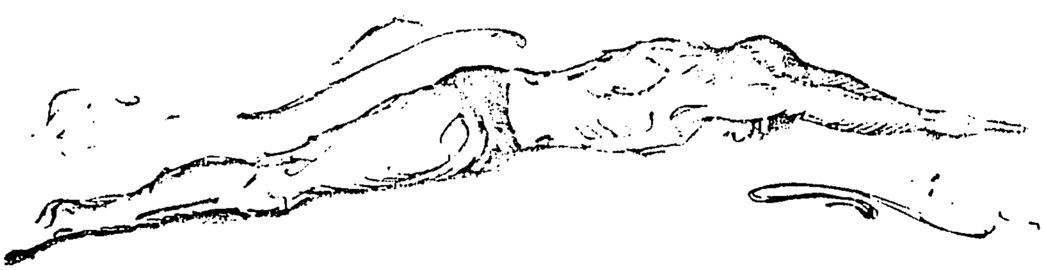
ATTENTION: **Triathletes**

(Past, Present & Future)

The Departments of Food & Nutrition, and Physical Education are sponsoring a TRIATHLON Club. If you are interested in joining, contact Dr. Terry Bazzarre or his staff

MEETING DATE: TUESDAY, NOVEMBER 13, 1984
7:00 P.M.
ROOM 328
SCHOOL OF HOME ECONOMICS
(STONE BLDG)

BENEFITS: TRAINING INFORMATION & SUPERVISION
TRAINING PARTNERS
TRAINING CLINICS
ASSESSMENT OF BODY FAT, CARDIOVASCULAR FITNESS, IRON STATUS, DIET AND BLOOD CHOLESTEROL
NUTRITION INFORMATION



APPENDIX B

CONSENT FORMS

UNC-G CLUB
TRIATHLON

Dr. Terry L. Bazzarre, Director
North Carolina Triathlon Club
School of Home Economics
University of North Carolina at Greensboro
Greensboro, North Carolina 27412

____
(Date)

Dear Dr. Bazzarre,

I have reviewed the medical records of

____
(Name of Triathlon Participant)

and reached the following opinion.

CHECK AS APPROPRIATE:

_____ May participate in the Triathlon Club without any known medical risk.

_____ May participate in the Triathlon Club only after the following tests have been satisfactorily completed

(1) _____ exercise stress test shceduled for the following date (Month ____ Day ____)

(2) _____ Other tests: (Please specify)

____

____

____ May not participate in the Triathlon Club because of the following medical problem(s).

Sincerely,

____
Physician's signature

____
Physician's Office Telephone Number

UNC-G CLUB TRIATHLON

Dear ______________________,
(Physician's Name)

I have agreed to release information concerning my past medical history to Dr. Terry Bazzarre, Director of the North Carolina Triathlon Club at the University of North Carolina at Greensboro. This medical information will be used for screening purposes to make sure that I am medically qualified to participate in an intensive 24-week endurance training program. Thank you.

North Carolina Triathlon Club Participant

____
(Name - PLEASE PRINT)

____
(Signature)

UNC-G CLUB TRIATHLON

Dear ________________________,

(Physician's Name)

________________________ is being screened for participation in the

(Participant's Name)

Triathlon Club at the University of North Carolina at Greensboro. The Triathlon Club is being sponsored by the departments of Nutrition and Physical Education. Part of our screening procedures require that we individually contact the physician of all participants over 35 years of age, and any participant who has known medical problems or risk factors (e.g. high blood pressure, elevated fasting cholesterol, angina, etc.) before they begin the program.

We would like you to review the medical records of the above participant, conduct any necessary tests, and complete the attached form. Please mail the completed form to:

Dr. Terry L. Bazzarre, Director
Laboratory of Nutrition and Human Performance
School of Home Economics
UNC-Greensboro
Greensboro, North Carolina 27412

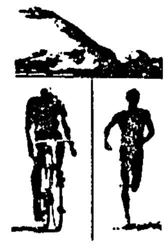
Dr. Jim Maultsby, a local physician and member of the North Carolina Triathlon Club could be contacted at his office if you have any questions regarding the medical concerns associated with triathlon training.

Thanks for your assistance.

Sincerely,

Terry L. Bazzarre, Ph.D.
Associate Professor

UNC-G CLUB TRIATHLON



CONSENT FORM

I agree to participate in a 24-week endurance training program. This program is being conducted by Dr. Terry Bazzarre and Dr. Karen Graves in the Nutrition Department and, by Dr. Richard Gayle and Dr. Diane Spitler in the Department of Physical Education at The Universtiy of North Carolina at Greensboro.

EXPLANATION OF STUDY

I understand that the purpose of the program is to evaluate the effects of a 24-week endurance training program on body weight, body fat, appetite, nutritional status and physical performance as well as on risk factors (total cholesterol, HDL-cholesterol and blood pressure) of participants. I understand that I will be required to complete a personal and family medical history in order to participate in the study, and that if I have a medical history of coronary heart disease, hypertension or diabetes that I will be screened from participation in the research. I understand that at the beginning of the study and at weeks 8,16, and 24 of the study, I will have approximately 30 ml of blood drawn from an ante-cubital vein in order to measure total cholesterol, HDL-cholesterol, iron status, zinc status and vitamin C status. At these same time intervals I will also have by blood pressure measured, and my body weight and percent body fat estimated. I also understand that I will complete a 7-day food record and a 7-day activity record at weeks 0,4,8,12,16,20 and 24 of the study.

I also understand that I will be asked to take an iron supplement or a placebo during the study. Neither I nor the investigator will know whether I am receiving the iron supplement until the end of the study. I understand that the investigators will inform me of any blood values that are indicative of true nutritional deficiencies, and that the investigators will refer me to my personal physician for appropriate follow-up evaluation.

I will also complete a 12-minute walk/ run test, a strength (grip) test, and a flexibility test at weeks 0,8,16 and 24 under the supervision of Dr. Richard Gayle and Dr. Diane Spitler in the Human Performance Laboratory at UNC-G.

EXPLANATION OF RISKS

I understand that I may experience some discomfort at times that is associated with physical exertion (training). The training program I will follow will be modified to meet my individual needs and fitness level; the program will be carefully monitored by the investigators in order to maximize the development of my endurance capacity without increasing my risk of injury. Other potential risks of the study are associated with emotional stress and venipuncture. The researchers have develped a triathlon club, training clinics and workshops and have also developed a list of training partners in order to reduce emotional stress. All precautions associated with venipuncture have been taken in order to reduce the risks of venipuncture (i.e., air emboli, infection, bruising and fainting). I understand that all data collected on my physical characteristics are considered confidential and will be kept in a file in Dr. Bazzarre's office with controlled access to each subject's file. Research analyses on all subjects' data will be performed using code numbers rather than subjects' names. I understand that physical training may alter sex hormone levels, and subsequently may alter the menstrual cycle of female subjects. The nature and significance of any of these changes is not known. Iron supplements may cause some gastro-intestinal discomfort.

I understand that I can withdraw from the study at <u>any</u> time of my choosing without prejudice from any of the investigators.

UNC-G CLUB TRIATHLON

CONSENT FORM CONTINUED

EXPLANATION OF BENEFITS

The benefits I may gain from participating in this study include: evaluation of my risk of developing heart disease, hypertension or nutritional problems; evaluation of my endurance capacity, strength, and flexibility; workshops and clinics on triathlon competition (swimming, biking and running); measurements of my body fat and lean body mass. I will also learn about training principles, physiological responses to exercise and the effects of endurance training on nutritional requirements. I will receive an individualized training program and log book as well as benefit from the group support provided by being a member of the North Carolina Triathlon Club.

I understand that Dr. Bazzarre, Dr. Graves, Dr. Gayle, Dr. Spitler or some other member of the investigative staff will be available to answer any questions I have. They can be reached at 919-379-5332 on weekdays. All of my immediate questions have been answered.

____ ________________

FULL LEGAL NAME DATE

APPENDIX C

RECOMMENDED TRAINING PROGRAM

SWIMMING*

LEVEL	I	II	III	IV
WEEK	< 1 mile/week	1-2 miles/week	2-4 miles/week	4-6 miles/week
1	10 laps X 3	18 laps X 3	27 laps X 3	600 X 1 Easy 200 X 2 Hard X 3 100 X 2 Easy
2	12 laps X 3	21 laps X 3	30 laps X 3	600 X 1 Easy 200 X 2 Hard 100 X 2 Easy X 3 100 X 2 Hard
3	14 laps X 3	24 laps X 3	33 laps X 3	600 X 1 Easy 400 X 2 Hard X 3 200 X 2 Easy
4	16 laps X 3	24 laps X 3	36 laps X 3	36 laps X 4
5	18 laps X 3	400 X 1 Easy 100 X 2 Hard X 3	400 X 1 Easy 200 X 2 Hard X 3 100 X 2 Hard	800 X 1 Easy 400 X 2 Hard X 3 200 X 2 Easy
6	20 laps X 3	400 X 1 Easy 200 X 1 Hard X 3 100 X 2 Hard	600 X 1 Easy 200 X 2 Hard X 3 100 X 2 Hard	800 X 1 Easy 400 X 2 Hard 200 X 2 Easy X 3 100 x 2 Hard
7	22 laps X 3	400 X 1 Easy 200 X 2 Hard X 3 100 X 2 Hard	600 X 1 Easy 200 X 2 Hard X 3 100 X 2 Easy 100 X 2 Hard	REPEAT WEEK 6
8	24 laps X 3	400 X 1 Easy 200 X 2 Hard 100 X 2 Easy X 3 50 X 4 Hard	REPEAT WEEK 7	900 X 1 Easy 300 X 2 Hard X 3 300 X 2 Easy

* Master's level + 6+ miles per week

note: 1 lap = 2 links (lengths) of a 25 yard or 25 meter pool

36 laps=1 mile

50= 2 laps   400= 16 laps
100= 4 laps   600= 24 laps
200=8 laps   900= 36 laps

BIKING*

LEVEL	I	II	III	IV
WEEK	< 10 miles/week	10-20 miles/week	30-60 miles/week	60-100 miles/week
1	20 minutes X 3	10 miles X 3	10 miles X 2 15-20 miles X 1	20 miles X 3 (timeX1)
2	30 minutes X 3	10 miles X 3	10 miles X 2 15-20 miles X 1	20 miles X 3 (timeX1)
3	30 minutes X 3	10 miles X 3	10 miles X 2 15-20 miles X 1	20 miles X 3
4	30 minutes X 2 45 minutes X 1	10 miles X 2 15-20 miles X 1	10 miles X 1 15-20 miles X 2	20 miles X 2 25 miles X 1 (timeX1)
5	30 minutes X 3	10 miles X 2 15-20 miles X 1	10 miles X 1 15-20 miles X 2	20 miles X 2 25 miles X 1 (timeX1)
6	45 minutes X 3	10 miles X 2 15-20 miles X 1	15 miles X 1 15-20 miles X 2	20 miles X 2 25 miles X 1
7	45 minutes X 3	15 miles X 3	15 miles X 1 15-20 miles X 2	25 miles X 3 (timeX1)
8	45 minutes X 2 60 minutes X 1	15 miles X 3	15-20 miles X 2 20 miles X 1	25 miles X 3 (timeX1)

* Master's level = 100+ miles per week

time= complete the workout by pushing to do the workout in the shortest time possible

RUNNING*

LEVEL	I	II	III	IV
WEEK	<10miles/week	10-20miles/week	20-40miles/week	40-60miles/week
1	20 min.X 3	4 miles X 3	6 miles X 4	10 miles X 4
2	25 min.X 3	5 miles X 3	6 miles X 3 10 miles X 1	10 miles X 4
3	30 min.X 4	6 miles X 3	6 miles X 3 10 miles X 1	6 miles X 2 (1H;1E) 10 miles X 2 (1H;1E)
4	35 min.X 3	6 miles X 4	6 miles X 2 10 miles X 2	6 miles X 2 (1H;1E) 10 miles X 2 (1H;1E)
5	40 min.X 3	6 miles X 3	6 miles X 2 10 miles X 2	14 miles X 1 10 miles X 3
6	45 min.X3	8 miles X 3	6 miles X 1 10 miles X 3	repeat week 5
7	50 min.X 4	8 miles X 3	6 miles X 1 10 miles X 3	repeat week 5
8	60 min.X 3	8 miles X 4	10 miles X 4	10 miles X 3 (1H;2E) 14 miles X 1
		race	race	race

* Master's level = 60+ miles/week

H= Hard

E= Easy

APPENDIX D

FOOD INTAKE

INSTRUCTIONS FOR A FOOD RECORD

These instructions will help you in recording the food that you eat. Please read these instructions carefully. If you have any questions. please feel free to call the ~~Deparment~~ of Foods and Nutrition at the University of North Carolina at Greensboro, 379-5332 or 379-5313

1. Measure each item using household measurements (cup, ½ cup, 1/3 cup 1/4 cup, tablespoon, teaspoon, 3/4 teaspoon, 1/2 teaspoon, 1/4 teaspoon, etc.). Abbreviations can be used.
   C=cup
   T= Tablespoon
   t= teaspoon

2. For items that are not measured such as fresh fruit or eggs, write the number of items eaten and whether they are large or small.
Examples:
   1 large egg
   1 small banana
   3 lumps sugar
Additional information about the sizeof the food such as diameter, length, width, thickness or ounces is helpful.
Examples:
   3" carrot
   1 Brownie with walnuts, wedge 2" by 2" by 1" high
   1 - 12 oz. can Coke
   Pizza with mushrooms, green pepper and cheese - 1/8 of 12" pizza
   1 apple - 2 1/2 " diameter

3. If you do not eat all the food you have served on your plate, try to measure the amount of <u>each</u> item you did not eat and subtract that amount from what was served.
Example: If you are served a peanut butter sandwich with two slices of bread and 2 T peanut butter and you eat 3/4 of the sandwich, you have eaten 1 1/2 slices of bread and 1 1/2 T of peanut butter.

4. Describe the food eaten as exactly as possible
   a. For meat fish, poultry and eggs specify the cut or type of meat or fish (chuck or bass), whether you ate or trimmed off the fat, whether you ate the skin (poultry), percent fat (hamburger) and whether the fish was oil pack or water pack (tuna).
   b. For breads, cereal, cakes, cookies, etc. state whether the food is made from white flour or whole grain and whether the food was homemade or bought. Specify the brand names whenever possible.
   c. For margarine state the brand name,whether the margarine comes as a stick, soft or liquid, whether it is diet or regular and whether it is whipped or not.
   d. For oils and shortening state the brand name, the major oil(s) (if known) and whether the fat is solid fat or oil.
   e. For salad dressings specify whether it is homemade, commercial or restaurant, the type of oil or brand name. creamy or clear, and additional ingredients such as cheese or bacon bites.
   f. For dairy products indicate the percent fat, the brand name or relative price and whether it is a true dairy product or a nondairy product.
   g. For bakery items state whether they are homemade, restaurant or commercial, the brand, the principal fat, toppings or frostings, yeast or cake and type of grain. For pies indicate whether it is a single or double crust.
   h. For sauces and gravies indicate the type of fat, the meat fat and what kind of milk added.
   i. For recipes and mixed dishes indicate whether it is homemade, commercial or restaurant, the brand name, cooking method and all ingredients used. Submit a recipe if possible.
   j. For fruits and juices indicate whether they are fresh, frozen, canned, cooked or dried; and whether the food is sweetened or unsweetened.
   h. For vegetables state whether they are cooked or raw, the kind of fat added if any, sauces added, the method cooked and any seasonings added. Specify how mashed potatoes were prepared.

l. For soups speecify whether they are homemade or canned, cream soups or clear soups and the water or kind of milk or stock added.

m. For beverages and cereals, indicate whether they are sweetened or unsweetened, diet-sweetened or unsweetened, the brand, decaffeinated (coffee or tea), and whether it is a cola or noncola.

n. For crackers, snacks, candy bars indicate the brand, weight , type or size.

If you are in doubt as to whether the information is needed or not, include the information.

5. Record accompaniments such as gravey, sauces, salad dressings, mayonaise, ketchup,mustard, seasonings, garnishes, etc. separately. Do not forget to record sugar, lemon, cream, non - dairy creamers or flavorings that you may add to drinks such as coffee, teas or milk. If you drink any liquid other than water, measure the amount in a liquid (pyrex) measuring cup. Or if you use the same cup or glass often, measure the amount of liquid the glass or cup will hold and fill to the samelevel with the beverage.

6. Describe how the food was prepared, including any additional fat, sugar or condiments that may be added.

Example:

sauteed in butter
basted with garlic butter
boiled in water
deep fat fried in peanut oil
simmered in wine

7. Do not forget to record snacks. If you eat a snack away from home carry the wrapping home with you as a reminder.

APPENDIX E

ENERGY EXPENDITURE

Table of Activity Categories for Assessing Daily Energy Expenditure

Category	Examples of Activities	Median Energy Cost METS	kcal/ kg BW/ 15 min
1	Sleeping Resting in bed	1.0	0.26
2	Sitting, eating, listening, writing, etc.	1.5	0.38
3	Light activity: standing, washing, shaving, cooking, etc.	2.3	0.57
4	Slow walk (less than 4 km/hr), driving, showering, etc.	2.8	0.69
5	Light manual work: floor sweeping, window washing, driving a truck, painting, waiting on tables, nursing chores, house chores, electrician, bartender, walking at 4 - 6 km/ hr.	3.3	0.84
6	Leisure activities and sports in a recreational environment: baseball, golf, volleyball archery, bowling, cycling at less than 10 km/ hr, table tennis, etc.	4.8	1.20
7	Manual work at a moderate pace: mining, carpentry, lumbering, snow shoveling, loading and unloading goods, etc.	5.6	1.40
8	Leisure and sport activities of higher intensity (non-competitive): canoeing (5-8 km/ hr.), cycling more than 15 km/ hr, dancing, skiing, badminton, gymnastics, swimming, tennis, horseback riding, walking more than 6 km/ hr, etc.	6.0	1.50
9	Intense manual work and high intensity sport activities: tree cutting, carrying heavy loads, backpacking, running more than 9 km/ hr, racquetball, swimming, cross country skiing more than 8 km/ hr, etc.	7.8	2.00
0	Leave blank for unusual circumstances		

Adapted from Bourchard et al, A.J. Clin Nutr. 37: 467, 1982.

DAILY ENERGY EXPENDITURE RECORD[1]

TRIATHLON STUDY

NAME ____________ Day of Week ______ Day of Month ______

AGE ______ Sex ______ Month ______ Year ______

Weight ____________

Directions:

Write in the space provided, the categorical value which corresponds best to the dominant activity of each 15-minute period.

Please consult the activity card to establish the proper coding.

In case of doubt, make a note and raise the question during the interview.

HOUR/ min	0 - 15	16 - 30	31 -45	46 - 60	HR *
Midnite					
1:00 a.m.					
2:00 a.m.					
3:00 a.m.					
4:00 a.m.					
5:00 a.m.					
6:00 a.m.					
7:00 a.m.					
8:00 a.m.					
9:00 a.m.					
10:00 a.m.					
11:00 a.m.					
12:00 Noon					
1:00 p.m.					
2:00 p.m.					
3:00 p.m.					
4:00 p.m.					
5:00 p.m.					
6:00 p.m.					
7:00 p.m.					
8:00 p.m.					
9:00 p.m.					
10:00 p.m.					
11:00 p.m.					

* - Record your heart rate (HR) at the end of any activity period ranked 7, 8 or 9 in this column.

Calculations: Total

1 = =

2 = =

3 = =

4 = =

5 = =

6 = =

7 = =

8 = =

9 = =

0 = =

GRAND TOTAL

1. Bourchard et al. A. J. Clin. Nut. 37: 467, 1982.

APPENDIX F

DEMOGRAPHIC AND ANTHROPOMETRIC FORMS

UNC-G TRIATHLON CLUB

NAME: ______________________ ADDRESS: ______________________

AGE: ____ SEX: ____ HEIGHT: ____ WEIGHT: ____ ______________________

GOALS: ______________________ TELEPHONE: HOME - ______________________

______________________ OFFICE - ______________________

______________________ PERSONAL PHYSICIAN ______________________

______________________ PHYSICIAN'S PHONE NUMBER ______________________

OCCUPATION: ______________________ MARITAL STATUS: single ____ married ____ div. ____

* *

MEDICAL HISTORY

	SELF	FATHER	MOTHER	SIBLING(s) # 1	# 2	# 3	#4	# 5
CHD	____	____	____	____	____	____	____	____
HYPERTENSION	____	____	____	____	____	____	____	____
DIABETES	____	____	____	____	____	____	____	____
OBESITY	____	____	____	____	____	____	____	____

SMOKING STATUS: NEVER ____ STOPPED ____ YEARS AGO YES ____ PACKS/ DAY FOR ____ YEARS

ALCOHOL CONSUMPTION: NEVER ____ BEER ____ PER WEEK; WINE ____ PER WEEK; MIXED DRINKS ____ PER WEEK

VITAMIN/ MINERAL SUPPLEMENTATION: NEVER ____ NOT NOW ____ YES ____

If yes, list brand name ________ Amount ____ Frequency/ day ____

IRON SUPPLEMENTATION: NEVER ____ NOT NOW ____ YES ____

If yes, list brand name ________ Amount ____ Frequency/ day ____

PROTEIN SUPPLEMENTATION: NEVER ____ NOT NOW ____ YES ____

If yes, list brand name ________ Amount ____ Frequency/ day ____

Do you consider yourself to be a vegetarian? NEVER ____ NOT NOW ____ YES ____

If yes, list your primary sources of protein ______________

* *

Have you had any training injuries during the past year: No ____ YES ____

If yes, describe the nature of the injury(s) and the treatment(s): ______________

____

____

____

UNC-G TRIATHLON CLUB

Anthropometric Data

TEST PERIOD	I	II	III	IV
Anthropometric Data:				
Height(cm)	____	____	____	____
Weight(kg)	____	____	____	____
Skinfolds(mm):				
Triceps	____	____	____	____
Biceps	____	____	____	____
Subscapular	____	____	____	____
Suprailiac	____	____	____	____
Sum 4 SF	____	____	____	____
Body Fat	____	____	____	____
Body Density	____	____	____	____
Body Fat	____	____	____	____
Circumferences:				
Mid-Upper Arm (cm)	____	____	____	____
MUA Fat Area (mm^2)	____	____	____	____
MUA Muscle Area (mm^2)	____	____	____	____
Chest (cm)				
Waist (cm)	____	____	____	____
Thigh (cm)	____	____	____	____

* *

NAME ______________________

AGE ____ SEX ____